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USA-Vec/DYNA3D User's Manual

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This report combines under one cover the user's instructions for the underwater shock analysis code USA and the explicit, nonlinear structural analysis code VecDYNA3D. USA/VecDYNA3D is the result of a close coupling of the two codes.

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SUMMARY

This is a users manual for the USA/VecDYNA3D code, which is a combination of the USA and VecDYNA3D codes. USA is a boundary element code for the determination of the transient response of submerged structures to acoustic shock waves of arbitrary pressure-profile and source location. It implements a family of fluid-structure interaction approximations known as the Doubly Asymptotic Approximations (DAA). VecDYNA3D is an explicit finite element code for the large deformation dynamic response of solids and structures. Spatial discretization is achieved by the use of solid elements, beam elements, thin and thick shell elements, and rigid bodies. It supports thirty material models and ten equations of state, and has contact-impact algorithms which permit gaps and sliding along material interfaces with friction.

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SECTION 1

INTRODUCTION

This manual lists the user instructions required to execute the USA-VecDYNA3D code. The manual is essentially a combination of the VecDYNA3D manual [Hallquist and Stillman] and the USA manual [DeRuntz]. Both USA and VecDYNA3D are the result of many man years of work at several sites under the sponsorship of several parties. Over the last five years, the Defense Nuclear Agency, the Carderock Division of the Naval Surface Warfare Center, and the Office of Naval Research have supported the interfacing, enhancement and validation of these codes for the large scale damage analysis of Naval structures and equipment.

USA-VecDYNA consists of three independently executable processors, USADYN, FLUMAS, and AUGMAT, plus a suite of post-processing tools. Execution of USA-VecDYNA is in the most general case a four step process. One first runs USADYN in a preprocessing phase, then runs USA's FLUMAS and AUGMAT preprocessors, and finally computes the time-dependent response of the coupled fluid-structure system with a USADYN restart. This fourth step is frequently repeated for several shot geometries. If no USA coupling is identified within the VecDYNA3D instruction deck, a standard VecDYNA3D solution will be conducted upon initiation of USADYN, and the other three steps are not required.

1.1 USADYN EXECUTION FOR PREPROCESSING.

In the initial preprocessing phase, USADYN is invoked with the execution line

usadyn [-m *nwords*] [i=*inf*] [o=*otf*] [g=*ptf*] [f=*thf*] [d=*dpf*] [a=*rrd*] [b=*rlf*]

where

inf = input file with DYNA3D model definition
otf = print file (default name d3hsp)
ptf = plot state database (default name d3plot)
thf = time history database (default name d3thdt)
dpf = restart dump file (default d3dump)
rrd = running restart database (default name runrsf)
rlf = plot state database for relaxation phase (default d3drlf)

Filenames must be unique and restricted to 6 characters, except *inf*, which may be 8 characters. Internal scratch space for both the DYNA and TIMINT halves of USADYN are shared. It is sized on the command line. The LS-DYNA3D convention memory=*nwords* is also honored. In addition to the print file, this execution will generate four databases of import to later stages of the underwater shock analysis. They are:

d3dump, and perhaps its descendents d3dump01, d3dump02, ...
d3plot, and perhaps its descendents d3plot01, d3plot02, ...
d3thdt, and perhaps its descendents d3thdt01, d3thdt02, ...
strnam

Descendents arise with large models and reflect the fact that a single state is so large it overflows to more than one member of DYNA's familied file system. The database strnam contains the preprocessing data needed by USA's FLUMAS and AUGMAT processors. USA refers to this database by the names strnam and grdnam. Since one only needs to run the preprocessing phase once, it it a good idea to collect the DYNA files into a single entity for later usage with the tar command

```
tar -cvf dyna1.tar d3dump* d3plot* d3thdt*
```

One then untars dyna1.tar before each subsequent shock analysis with this structural model.

If hydrostatic loads are being applied to the model with dynamic relaxation, it will be done in pseudo time during this preprocessing phase. The d3dump database will then reflect this preloaded state. The behavior of the model during a relaxation phase is optionally stored for plotting on the d3drlf database.

1.2 FLUMAS EXECUTION FOR FLUID BOUNDARY MASS CALCULATION.

The FLUMAS processor is used to compute the fluid boundary mass matrix appearing in the DAA equations. It is invoked with the command

flumas [-m *nwords*] <flumas.inp >flumas.prt

where memory is allocated dynamically as above, and the input and print have been redirected to flumas.inp and flumas.prt. These file names may take any form the user chooses. FLUMAS will need the strnam database generated during the DYNA preprocessing phase, and will typically generate two databases of its own: geonam and flunam. The former contains the geometry of the fluid boundary mesh and the latter contains the fully coupled, symmetric fluid mass matrix. If the cavitating fluid analyzer CFA is going to be used to treat internal or external fluid, the potential fluid volume element database cavnam must be provided by the user. One needs to rerun FLUMAS only if either the geometry or connectivity of the structural model is changed. Changing the mass of the structure or revising DYNA material models does not require a recalculation of the fluid mass matrix.

1.3 AUGMAT EXECUTION FOR FORMATION OF DAA EQUATIONS.

The AUGMAT processor is used to calculate the augmented system of DAA equations to be used in the coupled fluid-structure solution. It is invoked with the command

augmat [-m *nwords*] <augmat.inp >augmat.prt

where memory is allocated dynamically as above, and the input and print have been redirected to augmat.inp and augmat.prt. AUGMAT will need the strnam, geonam, and flunam databases identified above and will generate its own database prenam. Prenam contains the coupled system of DAA equations. One must rerun AUGMAT whenever the fluid model changes, the structural mass changes, or a different DAA formulation is wanted.

1.4 USADYN RESTART FOR UNDERWATER SHOCK ANALYSIS.

The actual time-integration phase is conducted upon restart of USADYN. Users of standalone USA will recognize this as the TIMINT stage. This step is taken with the command

usadyn [-m *nwords*] r=*rtf* [i=*inf*] usa=timint.inp

where scratch space is allocated as before, *rtf* is the aforementioned d3dump file set, *inf* is the optional restart deck, and timint.inp is the file containing the TIMINT inputs. In this step USADYN requires the databases d3dump, d3plot, and d3thdt generated in the preprocessing step, and the USA databases strnam and prenam. If the cavitating fluid analyzer CFA is being used, the potential fluid volume element database cavnam is also required. USADYN will append plot states and time-history response data to the databases d3plot and d3thdt respectively. If requested, USADYN will save its response data, including fluid surface pressures.and cavitating volume element pressures on the posnam database. This practice is discouraged, however, since in reasonably sized models posnam becomes enormous. At the conclusion of the time-integration USADYN will make a restart dump of the structural model to the next logical members of the d3dump group. Restarts of USADYN in mid solution are not supported at this time.

1.5 USADYN RESTART FOR UNDERWATER SHOCK ANALYSIS WITH RESIDUAL DAMAGE.

Restarting with residual damage presumes an existing solution generated with at least the prior four steps. It also requires the d3dump restart database dumped by USADYN at the end of the prior underwater shock analysis. Then an analysis with residual damage is conducted with two more steps. First the residual relaxation step

usadyn [-m *nwords*] r=*rtf* i=*inf*

where rtf is the restart database set from the previous USA solution and inf is the DYNA restart deck. With a full deck restart of this type the material history will be preserved, relaxation loads can be reapplied, residual velocities damped out, and a new strnam database generated with the deformed geometry. This strnam database can be used in the regeneration of the geonam, flunam, and prenam databases, if the user feels it is justified. The second time-integration step with residual damage then proceeds as before, except the d3dump members used in this time-integration are those dumped by USADYN in the residual relaxation step, not the initial preprocessing step.

SECTION 2

VecDYNA3D USER INSTRUCTIONS

VecDYNA3D is an extension of DYNA3D (Hallquist), a widely used three dimensional code for the explicit analysis of large deformation, inelastic solid and structural dynamics. Spatial discretization in the code is achieved by the use of 8-node solid elements, 2-node beam elements, 3-node and 4-node shell elements, 8-node solid shell elements, rigid bodies, and various discrete mass, spring, and dashpot elements. Underintegration with hourglass control is used in most element classes. The code supports 30 different material models, 11 equations of state, and 10 sliding interface options for contact/impact.

2.1 TITLE CARD (12A6,A2,1X,A5).

Columns	Quantity	Format
1-72	Heading to appear on output	12A6
73-74	Input code version EQ.88: input follows this manual	A2
76-80	Large format option (default in INGRID, use if node numbers exceed 99999) input "LARGE"	A5

2.2 CONTROL CARDS.

Card 1
(I5,5I10)

Columns	Quantity	Format
1-5	Number of materials (NUMMAT)	I5
6-15	Number of nodal points (NUMNP)	I10
16-25	Number of solid hexahedron elements (NUMELH)	I10
26-35	Number of beam elements (NUMELB)	I10
36-45	Number of 4-node shell elements (NUMELS)	I10
46-55	Number of 8-node solid shell elements (NUMELT)	I10
56-65	Number of interface segments for linking (NUMIFS)	I10
66-75	Output interval for interface file	E10.0
76-80	Factor for minimum shell element time step	E5.0

Card 2
(6I5)

Columns	Quantity	Format
1-5	Number of nodal time history blocks (≤ 2000)	I5
6-10	Number of hexahedron element time history blocks (≤ 2000)	I5
11-15	Number of beam element time history blocks (≤ 2000)	I5
16-20	Number of shell element time history blocks (≤ 2000)	I5
21-25	Number of thick shell element time history blocks (≤ 2000)	I5
26-30	Problem status report interval EQ.0: default set to 1000	
31-35	Number of nodal rigid body constraint sets (NUMRBS)	I5

Time history blocks are the preferred way to save response data for x-y plotting. The save frequency is determined by the d3thdt dump interval specified on the fifth control card.

Nodal rigid body constraint sets allow one to tie nodes together with rigid arms.

Card 3
(6I5,A5)

Columns	Quantity	Format
1-5	Number of nodes in DYNA3D-JOY interface	I5
6-10	Number of sliding boundary planes	I5
11-15	Number of symmetry planes with failure	I5
16-20	Number of points in density vs depth curve (NUMDP)	I5
21-25	Brode function flag EQ.0: Brode parameters are not defined EQ.1: Brode parameters are defined in input	I5
26-30	Number of rigid body merge cards	I5
31-35	Nodal coordinate format: either E10.0 or E20.0	A5
36-40	Number of cross section definitions for force output (NUMCSD)	I5
41-50	Output interval for cross section forces	E10.0
51-55	Number of USA wet surfaces (NUSA)	I5
56-60	Number of nodes in contact with USA SOR elements (NUSAB)	I5
61-70	Knockdown factor for shell rotary mass terms	E10.0

If either NUSA or NUSAB is nonzero, then coupling with the USA code is assumed. NUSA is the number of wet surfaces seen by DYNA3D and so always reflects a one-to-one overlay scheme. Allowance is made for two-to-one and four-to-one overlays from within the USA flumas processor.

In general, one should not alter the rotary mass terms assigned to shell elements by DYNA3D. However, if one suspects artificial high frequency behavior caused by inflated inertias, they can be reduced with this factor with a concomitant reduction in time step size.

Card 4 (16I5)

Columns	Quantity	Format
1-5	Number of load curves	I5
6-10	Number of concentrated nodal loads	I5
11-15	Number of element sides having pressure loads applied	I5
16-20	Number of velocity/acceleration boundary condition cards	I5
21-25	Number of rigid walls (stonewalls)	I5
26-30	Number of nodal constraint cards	I5
31-35	Initial condition parameter I5 EQ.0: initialize velocities to zero EQ.1: initial velocities are read in	
36-40	Number of sliding interfaces, lNUMSIl LT.0: eroding contact logic activated	I5
41-45	Base acceleration in x-direction EQ.0: no EQ.1: yes	I5
46-50	Base acceleration in y-direction EQ.0: no EQ.1: yes	I5
51-55	Base acceleration in z-direction EQ.0: no EQ.1: yes	I5
56-60	Angular velocity about x-axis EQ.0: no EQ.1: yes	I5
61-65	Angular velocity about y-axis EQ.0: no EQ.1: yes	I5
66-70	Angular velocity about z-axis EQ.0: no EQ.1: yes	I5
71-75	Number of solid hexahedron elements for momentum deposition	I5
76-80	Number of detonation points	I5

Card 5 (3E10.0,2I5,2E10.0,2I5,E10.0)

Columns	Quantity	Format
1-10	Termination time	E10.0
11-20	Time interval between dumps of time history data (d3thdt)	E10.0
21-30	Time interval between complete state dumps and interface force databases (d3plot)	E10.0
31-35	Number of time steps between restart dump files	I5
36-40	Number of time steps between running restart dumps	I5
41-50	Initial time step size EQ.0.0: DYNA3D determines initial step size	E10.0
51-60	Scale factor for sliding interface penalties EQ.0.0: default = .10	E10.0
61-65	Thermal effects option EQ.0: no thermal effects EQ.n: temperature-time history is defined by load curve n LT.0: nodal temperatures are defined in TOPAZ3D generated disk files	I5
66-70	Reset default viscosities, IRQ EQ.1: new defaults are read on Card 9	I5
71-80	Scale factor for computed time step, SCFT (Default = .90; if high explosives are used, the default is lowered to .67)	E10.0

Card 6 (15I5)

Columns	Quantity	Format
1-5	Number of joint definitions	I5
6-10	Number of rigid bodies for which extra nodes are defined	I5
11-15	Number of shell-solid element interface definitions	I5
16-20	Number of tie-breaking shell slidelines, (NTBSL)	I5
21-25	Number of tied node sets with failure definitions, (NTNWF)	I5
26-30	Load curve number that limits maximum time step size. Optional, but often used to synchronize with USA.	I5
31-35	FLAG = 1 for springs, dampers, and lumped mass input, (INPSD)	I5
36-40	Number of rigid bodies for which inertial properties are defined	I5
41-45	FLAG = 1 to dump shell strain tensors at inner and outer surface for plotting by TAURUS. Usually 1.	I5
56-60	Hughes-Liu shell normal update option EQ.-2: unique nodal fibers EQ.-1: compute normals each cycle EQ.0: default set to -1 EQ.1: compute on restarts EQ.n: compute every n cycles	I5
61-65	Shell thickness change option EQ.0: no change EQ.1: membrane straining causes thickness change	I5
66-70	Shell theory EQ.1: Hughes-Liu EQ.2: Belytschko-Tsay (default)	I5
71-75	Number of nonreflecting boundary segments (NNRBS)	I5

The use of a load curve to limit DYNA3D's time step is encouraged, since USA is expected to take time steps which are the same or larger than DYNA3D's. Ratios of 1:1 to 5:1 are fairly typical.

Card 7 (2I5,E10.0,5I5,2E10.0,2I5)

Columns	Quantity	Format
1-5	Number of single point constraint nodes (NODSPC)	I5
6-10	Number of coordinate systems for single point constraints (NSPCOR)	I5
11-20	Reduction factor for initial time step size to determine minimum step (TSMIN). DTMIN=DTSTART*TSMIN where DTSTART is the initial step size determined by DYNA3D. When TSMIN is reached DYNA3D terminates with a restart dump.	E10.0
21-25	Number of user specified beam integration rules (NUSBIR)	I5
26-30	Maximum number of integration points required in the user specified rules for beam elements	I5
31-35	Number of user specified shell integration rules (NUSSIR)	I5
36-40	Maximum number of integration, points required in the user specified rules for shell elements	I5
41-45	Number of iterations between convergence checks, for dynamic relaxation option (default=250). Relaxation is not invoked unless a load curve is defined with the relaxation flag set.	I5
46-55	Convergence tolerance for dynamic relaxation option (default=0.001)	E10.0
56-65	Dynamic relaxation factor D_r (default=.995)	E10.0
66-75	Scale factor for computed time step during dynamic relaxation; if zero, the value is set to SCFT defined on Card 5. After converging, the scale factor is reset to SCFT.	I5
76-80	Basis of time step size calculation for 4-node shell elements EQ.0: characteristic length=area/(longest side) EQ.1: characteristic length=area/(longest diagonal) EQ.2: based on bar wave speed and max (shortest side, area/longest side)	I5

Dynamic relaxation parameters are highly problem dependent and should be set cautiously. However, if one knows the time step size and can estimate the fundamental frequency of the model, then superior dynamic relaxation performance can often be obtained. Given a fundamental frequency of f_1 and time step Δt, the optimal choice of D_r is $1 - 4\pi f_1 \Delta t$.

Card 8 (9I5)

Columns	Quantity	Format
1-5	Plane stress plasticity option EQ.1: iterative plasticity with 3 secant iterations (default) EQ.2: full iterative plasticity EQ.3: radial return noniterative plasticity	I5
6-10	Printout flag for element time step sizes on the first cycle EQ.1: the governing time step sizes for each element is printed	I5
11-15	Number of 1D slideline definitions	I5
16-20	TAURUS database during dynamic relaxation option EQ.0: database is not written EQ.1: TAURUS database state for each convergence check	I5
21-25	Number of additional integration points history variables written to the Taurus database for solid elements	I5
26-30	Number of additional integration points history variables written to the TAURUS database for shell elements for each integration point.	I5
31-35	Number of shell integration points written to the TAURUS database (default = 3)	I5
36-40	Composite material stress output EQ.0: global EQ.1: local	I5
41-45	Dynamic relaxation/stress initialization flag EQ.1: via dynamic relaxation with loads flagged on load curves EQ.2: link to another database from an implicit calculation	I5
46-55	Print interval for AVS database	E10.0
56-60	Load curve number for system damping constant, (LCDAMP) EQ.0: no damping EQ.n: mass proportional damping given by load curve n.	I5
61-70	Mass proportional system damping constant, d, (this option is bypassed if the load curve number defined above in nonzero.)	E10.0
71-75	Number of user defined material subroutines, (NUMUMT)	I5
76-80	Number of beam integration points written to TAURUS database for stress history plots.	I5

Stress initialization in DYNA3D for small strains may be accomplished by linking to an implicit code. A displacement state is required that gives for each nodal point its label, xyz displacements, and xyz rotations. This data is read from unit 7 with the format (I8,6E15.0).

Cards 9,...,9+NUMUMT-1
(6I5)

Define the following control cards if and only if NUMUMT is nonzero.

Columns	Quantity	Format
1-5	Material type number between 41 and 50 inclusive	I5
6-10	Length of material constants array, i.e., number of constants to be read	I5
11-15	Number of history variables required (stresses are stored by default)	I5
16-20	Address of coordinate system definition in material constants array	I5
21-25	Address of bulk modulus in material constants array	I5
26-30	Address of shear modulus in material constants array	I5

One card is required for each user defined material subroutine. The number of history variables is arbitrary and can be any number greater than or equal to 0. The coordinate system definition is optional but is probably necessary if the model involves materials that have directional properties such as composites and anisotropic plasticity models. When the coordinate system option is used then all data passed to the constitutive model is in the local system. A bulk modulus and shear modulus are required for transmitting boundaries, contact interfaces, rigid body constraints, and time step size calculations. The number of constants read in columns 6-10 include the eight values for the coordinate system option if it is nonzero and two values for the bulk and shear modulus.

Card 9+NUMUMT
Optional Default Q Card (I5,E10.0,I5,2E10.0)
(define if IRQ=1)

Columns	Quantity	Format
1-5	Hourglass viscosity type, IHQ EQ.0: default=1 EQ.1: standard DYNA3D EQ.2: Flanagan-Belytschko EQ.3: Flanagan-Belytschko with exact volume integration EQ.4: stiffness form of type 2 (Flanagan-Belytschko) EQ.5: stiffness form of type 3 (Flanagan-Belytschko)	I5
5-15	Hourglass coefficient, QH (default=.10) Values of QH that exceed .15 may cause instabilities. The recommended default applies to all options The stiffness forms, however, can stiffen the response especially if deformations are large and therefore should be used with care.	E10.0
16-20	Bulk viscosity type, (IBQ) I5 EQ.0: default=1 EQ.1: standard DYNA3D	
21-30	Quadratic viscosity coefficient, Q1 (default=1.5)	E10.0
31-40	Linear viscosity coefficient, Q2 (default = .06)	E10.0

2.3 MATERIAL CARDS.

Repeat the following cards for each material model

Card 1 (2I5,E10.0,2I5,E10.0,I5,2E10.0,3I5)

Columns	Quantity	Format
1-5	Material identification number (< NUMMAT+1)	I5
6-10	Material type, MT. The numbers in brackets identify the element types for which the material is available: 0-solid, 1-beam, 2-shell, and 3-thick shell. EQ. 1: elastic [0,1,2,3] EQ. 2: orthotropic elastic [0,2,3] EQ. 3: kinematic/isotropic plasticity [0,1,2,3] EQ. 4: thermo-elastic-plastic [0,2,3] EQ. 5: soil and crushable foam [0] EQ. 6: viscoelastic [0] EQ. 7: rubber [0] EQ. 8: high explosive burn [0] EQ. 9: hydrodynamic without deviatoric stresses [0] EQ.10: elasto-plastic hydrodynamic [0] EQ.11: temperature dependent elastoplastic [0] EQ.12: isotropic elastoplastic [0,2,3] EQ.13: isotropic elastoplastic with failure [0] EQ.14: soil and crushable foam with failure [0] EQ.15: Johnson/Cook plasticity model [0,2,3] EQ.16: pseudo TENSOR geological model [0] EQ.17: elastoplastic with fracture [0] EQ.18: power law isotropic plasticity [0] EQ.19: strain rate dependent plasticity [0,2,3] EQ.20: rigid [0,2,3] EQ.21: thermal orthotropic with 12 constants [0,2,3] EQ.22: composite damage model [0,2,3 EQ.23: thermal orthotropic with 12 curves [0,2,3] EQ.24: piecewise linear isotropic plasticity [0,2,3 EQ.25: inviscid, two invariant geologic cap model [0] EQ.26: orthotropic crushable model [0] EQ.27: Mooney-Rivlin rubber [0] EQ.28: resultant plasticity [1,2,3] EQ.30: closed form update shell plasticity [2,3] EQ.31: Frazer-Nash rubber model [0] EQ.41-50: user defined materials	I5
11-20	Mass density	E10.0

Columns	Quantity	Format
21-25	Equation of state type. Define for material types 8, 9, 10, 11, 15, 16, 17, and 18 when these materials are used with solid materials EQ. 1: linear polynomial EQ. 2: JWL high explosive EQ. 3: Sack "Tuesday" high explosive EQ. 4: Gruneisen EQ. 5: ratio of polynomials EQ. 6: linear polynomial with energy deposition EQ. 7: ignition and growth of reaction in HE EQ. 8: tabulated compaction EQ. 9: tabulated EQ.11: TENSOR pore collapse	I5
26-30	Hourglass viscosity type, (IHQ) EQ. 0: default=1 EQ. 1: standard DYNA3D EQ. 2: Flanagan-Belytschko integration EQ. 3: Flanagan-Belytschko with exact volume integration EQ. 4: stiffness form of type 2 (Flanagan-Belytschko) EQ. 5: stiffness form of type 3 (Flanagan-Belytschko)	I5
31-40	Hourglass coefficient, QH (default = .10). Values of QH that exceed .15 may cause instabilities. The recommended default applies to all options. The stiffness forms, however, can stiffen the response especially if deformations are large and therefore should be used with care.	E10.0
41-45	Bulk viscosity type, (IBQ) I5 EQ. 0: default=1 EQ. 1: standard DYNA3D	
46-55	Quadratic viscosity coefficient, Q1 (default=1.5)	E10.0
56-65	Linear viscosity coefficient, Q2, (default=.06)	E10.0
66-70	Element class for which this material model is valid EQ. 0: solid hexahedron EQ. 1: beam EQ. 2: shell EQ. 3: thick shell	I5
71-75	Material initialization for gravity loading EQ. 0: all initialized EQ. 1: only current material is initialized	I5

Columns	Quantity	Format
76-80	Element formulation if other than default	I5
	For beam elements: EQ. 1: Hughes-Liu EQ. 2: Belytschko-Schwer EQ. 3: Truss	
	For shell elements: EQ. 1: Hughes-Liu shell EQ. 2: Belytschko-Tsay shell EQ. 3: BCIZ triangular shell EQ. 4: C^0 triangular shell EQ. 5: Belytschko-Tsay membrane EQ. 6: Belytschko-Leviathan shell	

Card 2 (12A6)

Columns	Quantity	Format
1-72	Material identification	12A6

Cards 3,4,5,....,8 (8E10.0

Material Type 1 (Elastic - Solid Elements)

Columns	Quantity		Format
1-10	Card 3	Young's modulus	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Blank	E10.0
1-10	Card 6	Blank	E10.0
1-10	Card 7	Blank	E10.0
1-10	Card 8	Blank	E10.0

Material Type 1 (Elastic - Lagrangian Acoustic Fluid Elements)

Columns	Quantity		Format
1-10	Card 3	Young's modulus	E10.0
1-10	Card 4	Poisson's ratio $\geq$ .49	E10.0
1-10	Card 5	Cavitation pressure	E10.0
1-10	Card 6	Blank	E10.0
1-10	Card 7	Blank	E10.0
1-10	Card 8	Blank	E10.0

Material Type 1 (Elastic - Beam Elements)

Columns		Quantity	Format
1-10	Card 3	Young's modulus	E10.0
11-20		Axial damping coefficient for H-L beams	E10.0
21-30		Transverse damping coefficent for H-L beams	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Blank	E10.0
1-10	Card 6	Blank	E10.0
1-10	Card 7	Blank	E10.0
1-10	Card 8	Blank	E10.0

Material Type 1 (Elastic - Shell Elements)

Columns		Quantity	Format
1-10	Card 3	Young's modulus	E10.0
11-20		Damping coefficient	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Blank	E10.0
1-10	Card 6	Blank	E10.0
1-10	Card 7	Blank	E10.0
1-10	Card 8	Blank	E10.0

Damping coefficients typically range from 0 to 1, and higher values are possible in some cases.

Material Type 2 (Orthotropic Elastic)

Columns		Quantity	Format
1-10	Card 3	E_a (see Figure 1)	E10.0
11-20		E_b	E10.0
21-30		E_c	E10.0
1-10	Card 4	ν_{ba}	E10.0
11-20		ν_{ca}	E10.0
21-30		ν_{cb}	E10.0
1-10	Card 5	G_{ab}	E10.0
11-20		G_{bc}	E10.0
21-30		G_{ca}	E10.0
1-10	Card 6	Material axes option, AOPT EQ.0.0: locally orthotropic with material axes determined by element nodes as shown in Figure 1. Cards 7 and 8 are blank with this option. EQ.1.0: locally orthotropic with material axes determined by a point in space and the global location of the element center. Card 8 below is blank EQ.2.0: globally orthotropic with material axes determined by vectors defined on Cards 7 and 8 EQ.3.0: applicable to shell elements only. This option determines locally orthotropic material axes by offsetting the material axes by an angle (Card 8) from a line in the plane of the shell determined by taking the cross product of the vector defined n Card 7 with the shell normal vector.	E10.0
1-10	Card 7	x_p, define for AOPT = 1.0	E10.0
11-20		y_p, define for AOPT = 1.0	E10.0
21-30		z_p, define for AOPT = 1.0	E10.0
1-10	Card 7	a_1, define for AOPT = 2.0	E10.0
11-20		a_2, define for AOPT = 2.0	E10.0
21-30		a_3, define for AOPT = 2.0	E10.0

Columns	Quantity			Format
1-10	Card 7	v_1,	define for AOPT = 3.0	E10.0
11-20		v_2,	define for AOPT = 3.0	E10.0
21-30		v_3,	define for AOPT = 3.0	E10.0
1-10	Card 8	d_1,	define for AOPT = 2.0	E10.0
11-20		d_2,	define for AOPT = 2.0	E10.0
21-30		d_3,	define for AOPT = 2.0	E10.0
1-10	Card 8	Material angle beta, may be overridden on the element card		E10.0

The material law that relates stresses to strains is defined as:

$$\underline{C} = \underline{T}^T \underline{C}_L \underline{T} \tag{2.1}$$

where $\underline{T}$ is a transformation matrix, and $\underline{C}_L$ is the constitutive matrix defined in terms of the material constants of the orthogonal material axes, a, b, and c.

$$\underline{C}_L^{-1} = \begin{bmatrix} \frac{1}{E_a} & -\frac{\upsilon_{ba}}{E_b} & -\frac{\upsilon_{ca}}{E_c} & 0 & 0 & 0 \\ -\frac{\upsilon_{ab}}{E_a} & \frac{1}{E_b} & -\frac{\upsilon_{cb}}{E_c} & 0 & 0 & 0 \\ -\frac{\upsilon_{ac}}{E_a} & -\frac{1}{E_b} & -\frac{\upsilon_{cb}}{E_c} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{ab}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{bc}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{ca}} \end{bmatrix}$$

Note that $\frac{\upsilon_{ab}}{E_a} = \frac{\upsilon_{ba}}{E_b} = \frac{\upsilon_{ca}}{E_c} = \frac{\upsilon_{ac}}{E_a} = \frac{\upsilon_{cb}}{E_c} = \frac{\upsilon_{bc}}{E_b}$

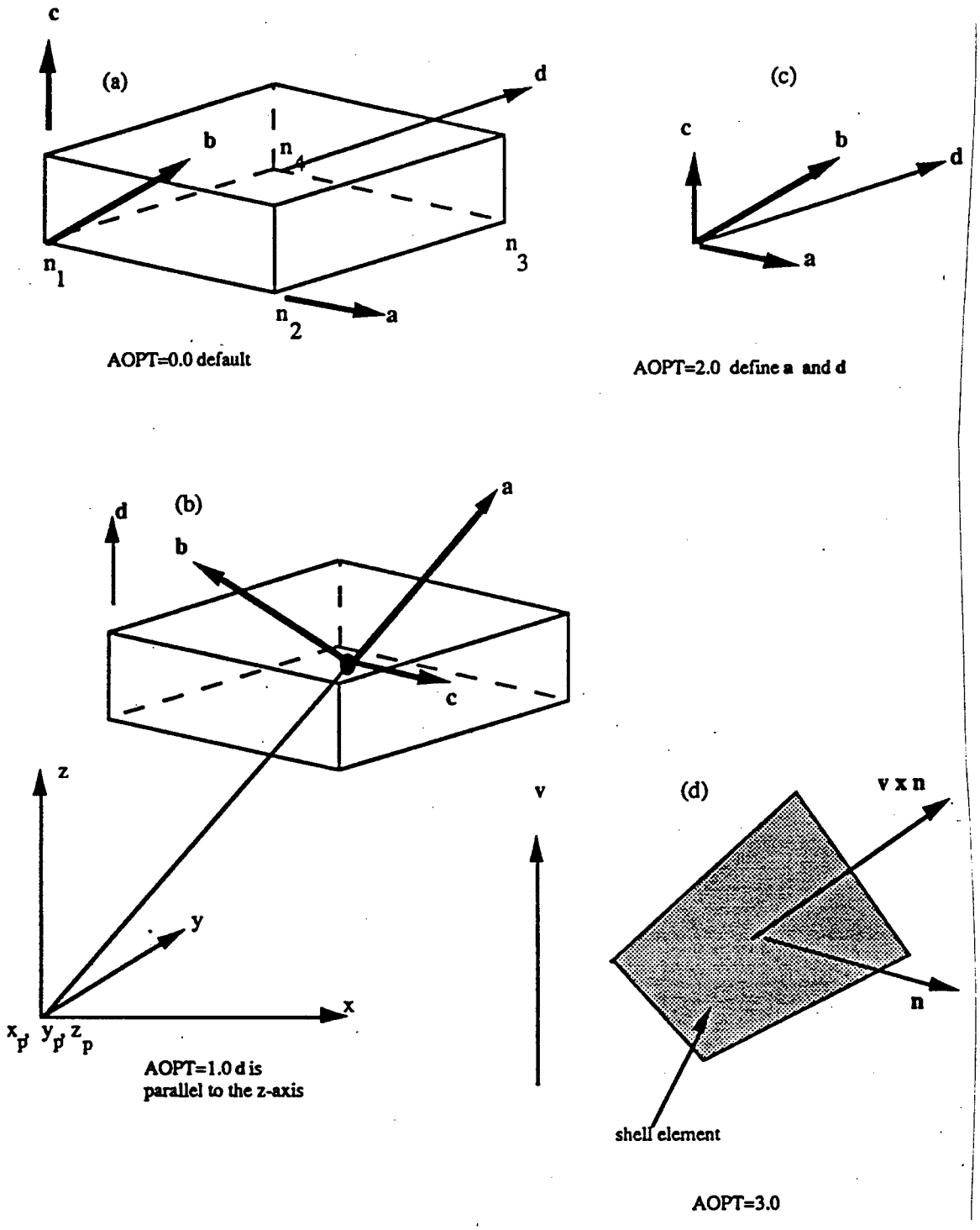


Figure 2-1. Options for determining principal material axes: (a) AOPT = 0.0, (b) AOPT = 1.0 (c) AOPT = 2.0, Note that $\underset{\sim}{c} = \underset{\sim}{a} \times \underset{\sim}{d}$ and that $\underset{\sim}{b} = \underset{\sim}{c} \times \underset{\sim}{a}$ and (d) AOPT = 3.0.

Material Type 3 (Kinematic/Isotropic Elastic-Plastic)

Columns		Quantity	Format
1-10	Card 3	Young's modulus	E10.0
11-20		Strain rate parameter, C	E10.0
21-30		Strain rate parameter, p	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Yield stress	E10.0
1-10	Card 6	Hardening modulus, E_t	E10.0
1-10	Card 7	Hardening parameter, β	E10.0
		$0 < \beta < 1$	
1-10	Card 8	Plastic strain for eroding failure	E10.0

Strain rate is accounted for using the Cowper and Symonds model which scales the yield stress with the factor

$$1 + (\dot{\varepsilon} / C)^{1/p} \tag{2.2}$$

where $\dot{\varepsilon}$ is the strain rate.

Kinematic, isotropic, or a combination of kinematic and isotropic hardening may be specified by varying β between 0 and 1. For β equal to 0 and 1, respectively, kinematic and isotropic hardening are obtained as shown in Figure 2. For isotropic hardening, $\beta = 1$, Material Model 12 requires less storage and is more efficient for solid elements.

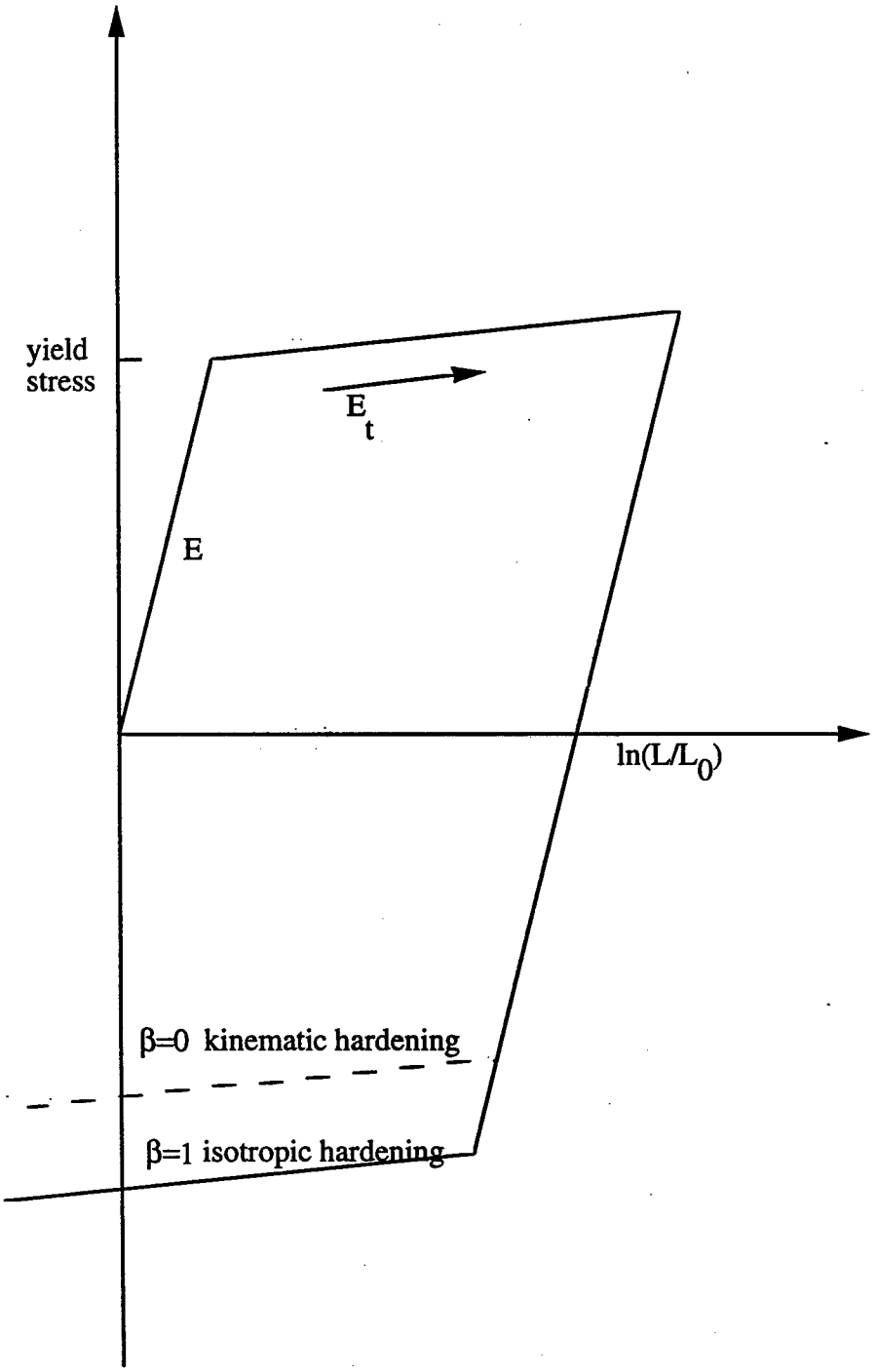


Figure 2-2. Elastic-plastic behavior with kinematic and isotropic hardening where L_0 and L are undeformed and deformed lengths of uniaxial tension specimen.

Material Type 4 (Thermo-Elastic-Plastic)

Columns		Quantity	Format
1-10	Card 3	T_1, temperature	E10.0
11-20		T_2	E10.0
.	.		.
.	.		.
.	.		.
71-80		T_8	E10.0
1-10	Card 4	E_1, Young's modulus at T_1	E10.0
11-20		E_2	E10.0
.	.		.
.	.		.
.	.		.
71-80		E_8	E10.0
1-10	Card 5	ν_1, Poisson's ratio at T_1	E10.0
11-20		ν_2	E10.0
.	.		.
.	.		.
.	.		.
71-80		ν_8	E10.0
1-10	Card 6	α_1, coefficient of thermal expansion at T_1	E10.0
11-20		α_2,	E10.0
.	.		.
.	.		.
.	.		.
71-80		α_8	E10.0
1-10	Card 7	σ_{y1}, yield stress at T_1	E10.0
11-20		σ_{y2},	E10.0
.	.		.
.	.		.
.	.		.
71-80		σ_{y8},	E10.0

Columns		Quantity	Format
1-10	Card 9	E^P_1 plastic hardening modulus at T_1	E10.0
11-20		E^P_2	E10.0
.	.		.
.	.		.
.	.		.
71-80		E^P_8	E10.0

At least two temperatures and their corresponding material properties must be defined. The analysis will be terminated if a material temperature falls outside the range defined in the input. If a thermo-elastic material is considered, leave Cards 7 and 8 blank. The coefficient of thermal expansion is defined with respect to the reference temperature at the beginning of the calculation for that material.

Material Type 5 (Soil and Crushable Foam)

Columns		Quantity	Format
1-10	Card 3	Shear modulus	E10.0
11-20		Bulk unloading modulus	E10.0
21-30		Yield function constant a_0	E10.0
31-40		Yield function constant a_1	E10.0
41-50		Yield function constant a_2	E10.0
51-60		Pressure cutoff for tensile fracture	E10.0
1-10	Card 4	Volumetric strain (see Figure 4)	E10.0
11-20		Pressure	E10.0
21-30		Volumetric strain	E10.0
31-40		Pressure	E10.0
1-10	Card 5	Volumetric strain	E10.0
11-20		Pressure	E10.0
21-30		Volumetric strain	E10.0
31-40		Pressure	E10.0
.	.		.
.	.		.
.	.		.
1-10	Card 8	Volumetric strain	E10.0
11-20		Pressure	E10.0
21-30		Volumetric strain	E10.0
31-40		Pressure	E10.0

Pressure is positive in compression. Volumetric strain is given by the natural log of the relative volume and is negative in compression. The tabulated data should be given in order of increasing compression. If the pressure drops below the cutoff value specified, it is reset to that value.

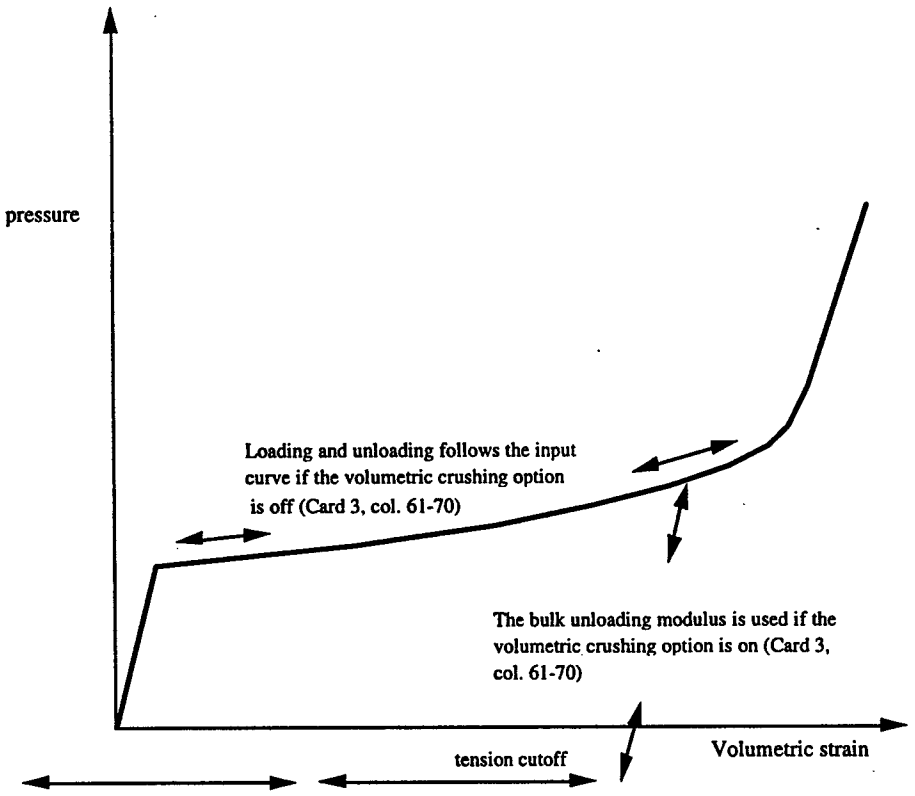


Figure 2-3. Volumetric strain vs. pressure curve for soil and crushable foam model.

The deviatoric perfectly plastic yield function, ϕ, is described in terms of the second invariant J_2,

$$J_2 = \frac{1}{2} s_{ij} \, s_{ij} \tag{2.3}$$

pressure, p, and constants a_0, a_1, and a_2 as:

$$\phi = J_2 - \left[a_0 + a_1 p + a_2 p^2\right] \quad . \tag{2.4}$$

On the yield surface $J_2 = \frac{1}{3} \sigma_y^2$ where σ_y is the uniaxial yield stress, i.e.,

$$\sigma_y = \left[3\left(a_0 + a_1 p + a_2 p^2\right)\right]^{\frac{1}{2}} \tag{2.5}$$

On this surface, there is no strain hardening. For no pressure hardening, $a_1 = a_2 = 0$, and $(3a_0)^{1/2}$ defines the yield strength.

The volumetric strain is given by the natural logarithm of the relative volume, V.

Material Type 6 (Viscoelastic Model)

Columns		Quantity	Format
1-10	Card 3	Bulk modulus (elastic)	E10.0
1-10	Card 4	Short-time shear modulus, G_0	E10.0
1-10	Card 5	Long-time shear modulus, G_∞	E10.0
1-10	Card 6	Decay constant, β	E10.0
1-10	Card 7	Blank	
	Card 8	Blank	

The shear relaxation behavior is described by:

$$G(t) = G_\infty + (G_0 - G_\infty)e^{-\beta t} \tag{2.6}$$

A Jaumann rate formulation is used

$$\overset{\nabla}{\sigma}{}'_{ij} = 2 \int_0^t G(t-\tau)\, D'_{ij}(\tau)\, d\tau \tag{2.7}$$

where the prime denotes the deviatoric part of the stress rate, $\overset{\nabla}{\sigma}_{ij}$, and the strain rate D_{ij}.

Material Type 7 (Blatz - Ko Rubber)

Columns	Quantity	Format
1-10	Card 3 Shear modulus, μ	E10.0
	Card 4 Blank	
.	.	.
.	.	.
.	.	.
	Card 8 Blank	

The second Piola-Kirchoff stress is computed as

$$S_{ij} = \mu \left(\frac{1}{v} C_{ij} - V^{\frac{-1}{1-2v}} \delta_{ij} \right) \tag{2.8}$$

where V is the relative volume, C_{ij} is the right Cauchy-Green strain tensor, and ν is Poisson's ratio which is set to .463 internally. This stress measure is transformed to the Cauchy stress, σ_{ij}, according to the relationship

$$\sigma_{ij} = V^{-1} F_{ik} F_{jl} S_{kl} \tag{2.9}$$

where F_{ij} is the deformation gradient tensor.

Material Type 8 (High Explosive Burn)

Columns	Quantity	Format
1-10	Card 3 D, Detonation velocity	E10.0
11-20	P_{CJ}, Chapman-Jouget pressure	E10.0
	Card 4 Blank	
	.	.
	.	.
	.	.
	Card 8 Blank	

Material Type 9 (Null Hydrodynamics)

Columns		Quantity	Format
1-10	Card 3	Pressure cutoff (≤ 0.0)	E10.0
11-20		Viscosity coefficient, μ	E10.0
	Card 4.	Blank	
	.		.
	.		.
	.		.
	Card 8	Blank	

The null material may be used with an equation-of-state. Pressure cutoff is negative in tension. A viscous stress of the form

$$\sigma_{ij} = \mu \dot{\varepsilon}'_{ij} \tag{2.10}$$

is computed for nonzero μ where $\dot{\varepsilon}'_{ij}$ is the deviatoric strain rate.

Material Type 10 (Isotropic-Elastic-Plastic-Hydrodynamic)

Columns		Quantity	Format
1-10	Card 3	Shear modulus	E10.0
11-20		Yield strength, σ_0	E10.0
21-30		Plastic hardening modulus, E_h	E10.0
31-40		Pressure cutoff (< 0.0) EQ.0.0: a cutoff of $-\infty$ is assumed	
1-10	Card 4	Plastic strain at failure	E10.0
1-10	Card 5	ε_1, effective plastic strain	E10.0
.		ε_2	.
.		ε_3	.
.		ε_4	.
41-50		ε_5	.
71-80		ε_8	E10.0
1-10	Card 6	ε_9	E10.0
	.		.
	.		.
	.		.
71-80		ε_{16}	E10.0
1-10	Card 7	σ_1 , effective stress	E10.0
.	.		.
.	.		.
.	.		.
41-80		σ_8	E10.0
1-10	Card 8	σ_9	E10.0
.	.		.
.	.		.
.	.		.
71-80		σ_{16}	E10.0

Whenever Cards 5-8 are blank, the yield stress and plastic hardening modulus are taken from Card 3. In this case, the bilinear stress-strain curve show in Figure 2. is obtained with $B' = 1$. The yield strength is calculated as

$$\sigma_y = \sigma_0 + E_h \varepsilon^{-p} \tag{2.11}$$

The quantity E_h is the plastic hardening modulus defined in terms of Young's modulus, E, and the tangent modulus, E_t, as follows

$$E_h = \frac{E_t E}{E - E_t}$$

If Cards 5-8 are used, a curve like that shown in Figure 4 may be defined. Effective stress is defined in terms of the deviatoric stress tensor, s_{ij}, as:

$$\bar{\sigma} = \left(\frac{3}{2} s_{ij} \; s_{ij} \right)^{\frac{1}{2}} \tag{2.12}$$

and effective plastic strain by:

$$\bar{\varepsilon}^p = \int_0^t \left(\frac{2}{3} D_{ij}^p \; D_{ij}^p \right)^{\frac{1}{2}} dt \quad , \tag{2.13}$$

where t denotes time and D_{ij}^p is the plastic component of the rate of deformation tensor. In this case the plastic hardening modulus on Card 3 is ignored and the yield stress is given as

$$\sigma_y = f\left(\bar{\varepsilon}^p \right) \quad , \tag{2.14}$$

where the value for $f\left(\bar{\varepsilon}^p\right)$ is found by interpolation from the data curve.

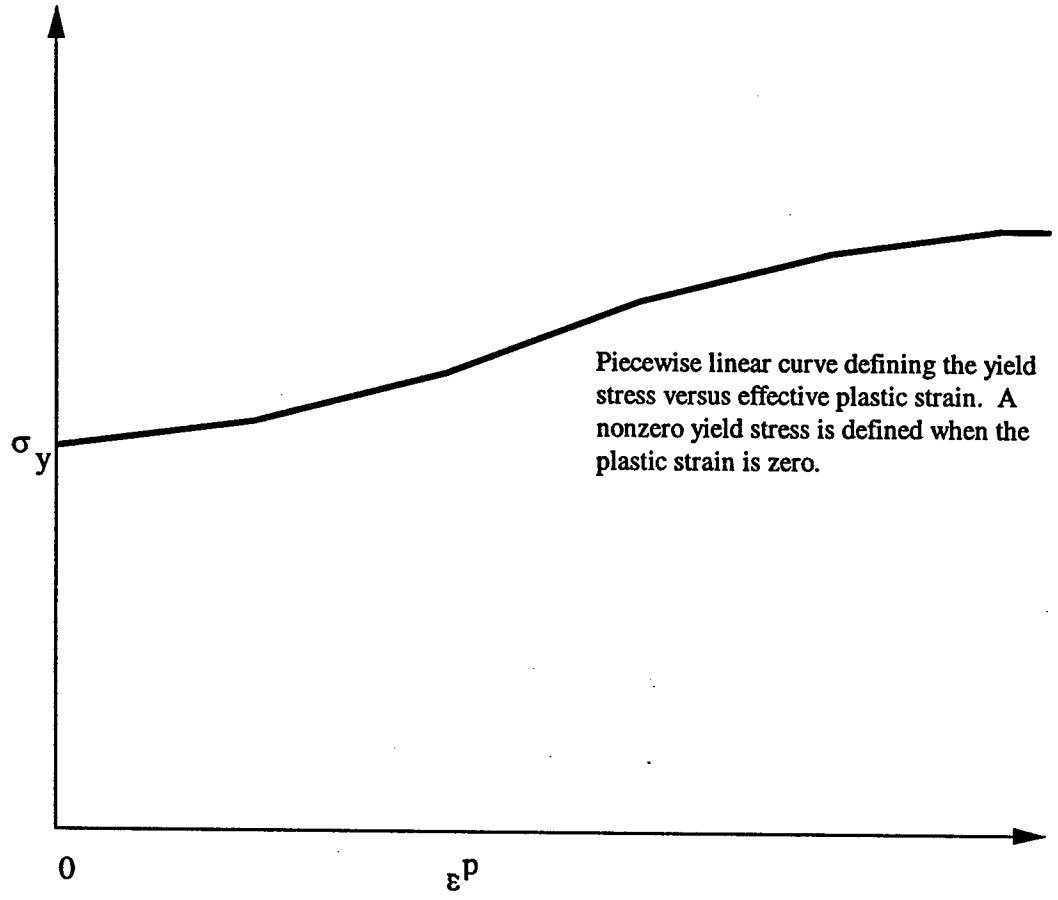


Figure 2-4. Effective stress vs. effective plastic strain curve.

Material Type 11 (Temperature Dependent, Elastoplastic, Hydrodynamic)

Columns		Quantity	Format
1-10	Card 3	G_0 Shear Modulus	E10.0
11-20		σ_0 Yield Stress	E10.0
21-30		β Hardening Coefficient	E10.0
31-40		n Hardening Exponent	E10.0
41-50		γ_i Initial Plastic Strain	E10.0
51-60		u_k*	E10.0
61-70		c_1* Strain Rate Effects Constant	E10.0
71-80		c_2* Strain Rate Effects Constant	E10.0
1-10	Card 4	σ_m Maximum Flow Stress	E10.0
11-20		b Shear Modulus Sensitivity to Volumetric Effects	E10.0
21-30		b′ Flow Stress Sensitivity to Volumetric Effects	E10.0
31-40		h	E10.0
41-50		f	E10.0
51-60		y_p* Peierls Stress	E10.0
1-10	Card 5	A (if = 0.0, R' must be defined)	E10.0
11-20		T_{mo} Melt Temperature	E10.0
21-30		γ_o	E10.0
31-40		a	E10.0
41-50		pmin Spall Stress	E10.0

*These constants are optional. If input, the Steinberg-Lund rate dependent model is used.

Material Type 11 (Temperature Dependent, Elastoplastic, Hydrodynamic) (Cont'd)

Columns		Quantity	Format
1-10	Card 6	Spall type EQ.0.0: default set to "2.0" EQ.1.0: $p \geqq p_{min}$ EQ.2.0: if $\sigma_{max} \geq$ -p min element spalls and tension, $p < 0$, is never allowed EQ.3.0: $p < -p_{min}$ element spalls and tension, $p < 0$, is never allowed	E10.0
11-20		R' (if $R' \neq 0.0$, A is not defined)	E10.0
41-50		FLAG = 1.0 for μ coefficients being supplied for cold compression energy fit.	E10.0
51-60		Optional μ or η minimum value	E10.0
61-70		Optional μ or η maximum value	E10.0
1-16	Card 7	$EC_0E16.0$	
17-32		$EC_1E16.0$	
33-48		$EC_2E16.0$	
49-64		$EC_3E16.0$	
65-80		$EC_4E16.0$	
1-16	Card 8	$EC_5E16.0$	
17-32		$EC_6E16.0$	
33-48		$EC_7E16.0$	
49-64		$EC_8E16.0$	
65-80		$EC_9E16.0$	

The original model (Steinberg and Guinan) was intended for high pressure events with strain-rates on the order of 10^5 to 10^6 1/sec. This occurs only for limited portions of high speed impact or explosive detonation experiments. The Steinber-Lund modification includes strain rate effects which they claim makes the model valid over the range necessary for most impact applications. Users who have an interest in this model are encouraged to study the paper (Steinberg and Guinan) which provides the theoretical basis.

In terms of the foregoing input parameters, we define the shear modulus, G, before the material melts as:

$$G = G_0\left[1 + bpV^{\frac{1}{3}} - h\left(\frac{E_i - E_c}{3R'} - 300\right)\right] e^{-\frac{fE_i}{E_m - E_i}} \tag{2.15}$$

where p is the pressure, V is the relative volume, E_c is the cold compression energy:

$$E_c(x) = \int_0^x p\,dx - \frac{900\,R'\exp(ax)}{(1-x)^{2\left(\gamma_0 - a - \frac{1}{2}\right)}}, \tag{2.16}$$

$$x = 1 - V,$$

and E_m is the melting energy:

$$E_m(x) = E_c(x) + 3R'T_m(x) \tag{2.17}$$

which is in terms of the melting temperature $T_m(x)$:

$$T_m(x) = \frac{T_{mo}\exp(2ax)}{V^{2\left(\gamma_o - a - \frac{1}{3}\right)}} \tag{2.18}$$

and the melting temperature at $\rho = \rho_0$, T_{mo}.

In the above equation R' is defined by

$$R' = \frac{R\rho}{A} \tag{2.19}$$

where R is the gas constant and A is the atomic weight. If R' is not defined, DYNA3D computes it with R in the cm-gram-microsecond system of units.

The yield strength σ_y is given by:

$$\sigma_y = \sigma_0'\left[1 + b'pV^{\frac{1}{3}} - h\left(\frac{E_i - E_c}{3R'} - 300\right)\right] e^{-\frac{fE_i}{E_m - E_i}} \tag{2.20}$$

if E_m exceeds E_i. Here, σ_0' is given by:

$$\sigma_y = \sigma_0'\left[1 + \beta\left(\gamma_i + \varepsilon^{-p}\right)\right]^n \tag{2.21}$$

where γ_i is the initial plastic strain. Whenever σ_0' exceeds σ_m, σ_0' is set equal to σ_m. After the materials melts, σ_y and G are set to zero.

If the coefficients EC0,...,EC9 are not defined above, DYNA3D will fit the cold compression energy to a ten term polynomial expansion:

$$E_c = \sum_{i=0}^{9} EC_i \eta^i \tag{2.22}$$

where EC_i is the ith coefficient and $\eta = \frac{\rho}{\rho_o} - 1$. The least squares method is used to perform the fit.

Material Type 12 (Isotropic-Elastic-Plastic)

Columns		Quantity	Format
1-10	Card 3	Shear modulus	E10.0
11-20		Yield stress (see Figure 2)	E10.0
21-30		Hardening modulus	E10.0
1-10	Card 4	K, bulk modulus	E10.0
	Card 5	Blank	
	•		
	•		
	•		
	Card 8	Blank	

Here the pressure is integrated in time

$$\dot{p} = -K \frac{\dot{V}}{V} \tag{2.23}$$

where V is the relative volume. This model is not recommended for shell elements.

Material Type 13 (Elastic-Plastic with Failure Model)

Columns		Quantity	Format
1-10	Card 3	Shear modulus	E10.0
11-20		Yield stress (see Figure 2)	E10.0
21-30		Hardening modulus	E10.0
31-40		Failure strain	E10.0
41-50		Failure pressure($\leq$ 0.0)	E10.0
1-10	Card 4	Bulk modulus	E10.0
	Card 5	Blank	
		.	
		.	
		.	
	Card 8	Blank	

When the effective plastic strain reaches the failure strain or when the pressure reaches the failure pressure, the element loses its ability to carry tension and the deviatoric stresses are set to zero, that is, the material behaves like a fluid.

Material Type 14 (Soil and Crushable Foam with Failure Model)

Columns		Quantity	Format
1-10	Card 3	Shear modulus	E10.0
11-20		Bulk unloading modulus	E10.0
21-30		Yield function constant a_0	E10.0
31-40		Yield function constant a_1	E10.0
41-50		Yield function constant a_2	E10.0
51-60		Pressure cutoff for tensile fracture	E10.0
1-10	Card 4	Volumetric strain (see Figure 3)	E10.0
11-20		Pressure	E10.0
21-30		Volumetric strain	E10.0
31-40		Pressure	E10.0
1-10	Card 5	Volumetric strain	E10.0
11-20		Pressure	E10.0
21-30		Volumetric strain	E10.0
31-40		Pressure	E10.0
.	.		.
.	.		.
.	.		.
1-10	Card 8	Volumetric strain	E10.0
11-20		Pressure	E10.0
21-30		Volumetric strain	E10.0
31-40		Pressure	E10.0

The input for this model is the same as for Material Type 5, however, when the pressure reaches the failure pressure, the element loses its ability to carry tension.

Material Type 15 (Johnson/Cook Strain and Temperature Sensitive Plasticity)

Columns		Quantity	Format
1-10	Card 3	G	E10.0
11-20		A	E10.0
21-30		B	E10.0
31-40		n	E10.0
41-50		C	E10.0
51-60		m	E10.0
61-70		Melt temperature, T_m	E10.0
71-80		Room temperature, T_r	E10.0
1-10	Card 4	ε_0	E10.0
11-20		Specific heat	E10.0
21-30		p_{min} or failure stress, σ_p	E10.0
31-40		Spall Type EQ.0.0: default set to "2.0" EQ.1.0: $p \geq p_{min}$ EQ.2.0: if $\sigma_{max} \geq \sigma_p$ element spalls and tension, $p \leq 0$, is never allowed EQ.3.0: if $p \leq p_{min}$ element spalls and tension, $p \leq 0$, is never allowed	E10.0
41-50		Plastic strain iteration flag EQ.1.0: accurate iterative solution for plastic strain. Much more expensive than default.	E10.0
1-10	Card 5	D1, failure parameter	E10.0
11-20		D2	E10.0
21-30		D3	E10.0
31-40		D4	E10.0
41-50		D5	E10.0

Columns	Quantity	Format
	Card 6 Blank	E10.0
	. .	
	. .	
	Card 8 Blank	E10.0

Johnson and Cook express the flow stress as

$$\sigma_y = \left(A + B\ \bar{\varepsilon}^{p^n}\right)\left(1 + c\ \ln \dot{\varepsilon}^*\right)\left(1 - T^{*m}\right) \tag{2.24}$$

where

A, B, C, n, and m = input constants

$\bar{\varepsilon}^p$ effective plastic strain

$\dot{\varepsilon}^* = \dfrac{\dot{\bar{\varepsilon}}^p}{\dot{\varepsilon}_0}$ effective plastic strain rate for $\varepsilon_0 = 1 s^{-1}$

T^* = homologous temperature

Constants for a variety of materials are provided in (Johnson and Cook).

Due to the nonlinearity in the dependence of flow stress on plastic strain, an accurate value of the flow stress requires iteration for the increment in plastic strain. However, by using a Taylor series expansion with linearization about the current time, we can solve for σ_y with sufficient accuracy to avoid iteration.

The strain at fracture is given by

$$\varepsilon^f = \left[D_1 + D_2 \exp\ D_3 \sigma^*\right]\left[1 + D_4\ \ln \dot{\varepsilon}^*\right]\left[1 + D_5 T^*\right] \tag{2.25}$$

where σ^* is the ratio of pressure divided by effective stress

$$\sigma^* = \frac{p}{\sigma_{eff}} \tag{2.26}$$

Fracture occurs when the damage parameter

$$D = \sum \frac{\Delta \bar{\varepsilon}^p}{\varepsilon^f} \tag{2.27}$$

reaches the value of 1.

Material Type 16 (Pseudo TENSOR Concrete/Geological Model)

Columns		Quantity	Format
1-10	Card 3	υ (constant Poisson's ratio model) or -G (constant shear modulus model)	E10.0
11-20		Tensile cutoff (maximum principal stress failure, sigf)	E10.0
21-30		Cohesion (a_0)	E10.0
31-40		Pressure hardening coefficient (a_1)	E10.0
41-50		Pressure hardening coefficient (a_2)	E10.0
51-60		Damage scaling factor b_1	E10.0
61-70		Cohesion for failed material (a0f)	E10.0
71-80		Pressure hardening coefficient for failed material (alf)	E10.0
1-10	Card 4	Percent reinforcement	E10.0
11-20		Elastic modulus for reinforcement	E10.0
21-30		Poisson's ratio for reinforcement	E10.0
31-40		Initial yield stress	E10.0
41-50		Tangent modulus	E10.0
51-60		Load curve giving rate sensitivity for principal material	E10.0
61-70		Load curve giving rate sensitivity for reinforcement	E10.0
1-10	Card 5	ε_1 effective plastic strain or pressure	E10.0
.	.		.
.	.		.
.	.		.
71-80		ε_8	E10.0
1-10	Card 6	ε_9	E10.0
.	.		.
.	.		.
.	.		.
71-80		ε_{16}	E10.0

Columns		Quantity	Format
1-10	Card 7	σ_1 , effective stress	E10.0
.	.		.
.	.		.
.	.		.
71-80		σ_8	E10.0
1-10	Card 8	σ_9	E10.0
.	.		.
.	.		.
.	.		.
71-80		σ_{16}	E10.0

For the constant Poisson's ratio model, the shear modulus is computed from the bulk modulus. For the constant shear modulus model, Poisson's ration is computed from the bulk modulus. The bulk modulus is determined by the equation of state.

If zero values are specified for a_0 and a_1 , the data on cards 5 and 6 are taken to be pressure values instead of values of effective plastic strain.

If a negative value is specified for a_0, the value given for sigf is assumed to be the unconfined compressive strength of the principal material instead of the tensile cutoff value. If this case, values for the tensile cutoff and pressure hardening coefficients are calculated internally as follows:

sigf = 1.7*((f'c)**2/ucf)**(1/3)
a_0 = (1/4) * (f'c)
a_1 = (1/3)
a_2 = (1/3) / (f'c)
a_{0f} = 0
a_{1c}= 0.385

where ucf = -a_0 is a unit conversion factor for f'c (psi/(DYNA pressure unit)).

A zero equation of state number can also be specified in this case and data for a tri-linear EOS8 model (good for pressures below approximately 5 kbars) will be generated internally using the values given for Poisson's ration and f'c. Otherwise, Equation of State 8, 9, or 11 must be specified and the corresponding data provided by the user.

Principal material and reinforcement properties are combined using a rule of mixtures as follows:

```
bulk = (1-fs)*bkm+fs*bkr
shrm = (1-fs)*gm+fs*gr
sigy = (1-fs)*sym+fs*syr
```

where

```
sym=f (k1,edot)*(a0+p/(a1+a2*p))*g(dmg) or f(k1,edot)*g(p)
```

and

```
syr=f (k2,edot)*qs+qh*epx.
```

f (k,edot) denotes the yield stress strain rate scaling factor obtained by linear interpolation from load curve k (if k=0, f=1.0), and g denotes either the damage or pressure scaling factor obtained by linear interpolation from the yield stress table. dmg is an isotropic measure of damage defined as

$$dmg = \int_0^{\bar{\varepsilon}^p} \frac{d\,\bar{\varepsilon}^p}{\left(1+\frac{p}{sigf}\right)^{**}b1} \quad ; \tag{2.28}$$

fs is the percent reinforcement which is treated isotropically.

If the maximum principal stress in an element exceeds the tensile cutoff, the matrix material in that element is assumed to have fractured. After fracture, the matrix material in an element can support only compressive loads and its shear strength is limited by the yield surface for failed material

```
symf=a0f+p/(a1f+a2*p).
```
(2.29)

Material Type 17 (Isotropic Elastic-Plastic Oriented Crack Model)

Columns	Quantity	Format
1-10	Card 3 Young's modulus	E10.0
1-10	Card 4 Poisson's ratio	E10.0
1-10	Card 5 Yield stress	E10.0
1-10	Card 6 Hardening modulus	E10.0
1-10	Card 7 Fracture strength	E10.0
1-10	Card 8 Pressure cutoff ($\leq 0.$)	E10.0

When the maximum principal stress exceeds the fracture stress, the element fails on a plane perpendicular to the direction of the maximum principal stress. In tension, the element will not carry any stresses on the fracture plane, but, in compression, it will carry both normal and shear stresses. If the fracture stress is exceeded in another direction, the element fails isotropically: the element loses its ability to carry tension, the deviatoric stresses are set to zero, and the material behaves as a fluid.

Material Type 18 (Power Law Isotopic Plasticity)

Columns		Quantity	Format
1-10	Card 3	Young's modulus	E10.0
11-20		Poisson's ratio	E10.0
21-30		k, strength coefficient	E10.0
31-40		n, hardening exponent	E10.0
	Card 4	Blank	
	Card 5	Blank	
		•	
		•	
		•	
	Card 8	Blank	

Elastoplastic behavior with isotropic hardening is provided by this model. The yield stress, σ_y, is a function of plastic strain and obeys the equation:

$$\sigma_y = k \left(\bar{\varepsilon}^p \right)^n \tag{2.30}$$

where $\bar{\varepsilon}^p$ is the effective plastic strain.

Material Type 19 (Strain Rate Dependent Isotropic Plasticity)

Columns		Quantity	Format
1-10	Card 3	Young's modulus	E10.0
11-20		Poisson's ratio	E10.0
21-30		Load curve number defining J_0 as a function of strain rate.	E10.0
31-40		Hardening modulus, E_t	E10.0
41-50		Load curve number (optional) defining Young's modulus as a function of strain rate	E10.0
51-60		Load curve number (optional) defining the tangent modulus as a function of strain rate	E10.0
61-70		Load curve number (optional) defining the von Mises stress at failure as a function of strain rate	E10.0
71-80		Time step size for automatic element deletion. (Shells only.)	E10.0
	Card 4	Blank	
	Card 5	Blank	
	•		
	•		
	•		
	Card 8	Blank	

In this model, a load curve is used to describe the yield strength, σ_0, as a function of effective strain rate, $\dot{\bar{\varepsilon}}$, where

$$\dot{\bar{\varepsilon}} = \left(\frac{2}{3} \dot{\varepsilon}'_{ij} \ \dot{\varepsilon}'_{ij} \right)^{1/2} \tag{2.31}$$

and the prime denotes the deviatoric component. The yield stress is defined as

$$\sigma_y = \sigma_0 \left(\dot{\bar{\varepsilon}} \right) + E_h \ \bar{\varepsilon}^p \tag{2.32}$$

where $\bar{\varepsilon}^p$ is the effective plastic strain and E_h is given by

$$E_h = \frac{E \ E_t}{E - E_t} \tag{2.33}$$

Material Type 20 (Rigid)

Columns	Quantity		Format
1-10	Card 3	Young's modulus	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Constraint flag: +1.0 for constraints	E10.0
1-10	Card 6	Translational constraint	E10.0
1-10	Card 7	Rotational constraint	E10.0
1-10	Card 8	Blank	E10.0

The material constants are used for determining sliding interface parameters if the rigid body interacts along sliding interfaces. Realistic values for these constants should be defined. Rigid material constraint should be applied here, rather than on nodal constraint cards. Constraint codes follow the same convention used with nodal constraints.

Material Type 21 (Thermal Orthotropic Elastic)

Columns		Quantity		Format
1-10	Card 3	E_a	(see Figure 1)	E10.0
11-20		E_b		E10.0
21-31		E_c		E10.0
1-10	Card 4	υ_{ba}		E10.0
11-20		υ_{ca}		E10.0
21-30		υ_{cb}		E10.0
31-40		α_{aa} ,	(coefficient of thermal expansion)	E10.0
41-50		α_{ab} ,		E10.0
51-60		α_{ac} ,		E10.0
1-10	Card 5	G_{ab}		E10.0
11-20		G_{bc}		E10.0
21-30		G_{ca}		E10.0
1-10	Card 6	Materials axes option AOPT		

EQ.0.0: locally orthotropic with material axes determined by element nodes n_1 , n_2 , and n_4 as shown in Figure 1

Card 7 and 8 below are blank with this option.

EQ.1.0: locally orthotropic with material axes determine by a point in space and the global location of the element center. Card 8 below is blank.

EQ.2.0: globally orthotropic with material axes determined by vectors defined on cards 7 and 8.

EQ.3.0: applicable to shell elements only. This option determines locally orthotropic material axes by offsetting the material axes by an angle (Card 8) from a line in the plane of the shell determined by taking the cross product of the vector defined on card 7.with the shell normal vector.

Columns		Quantity	Format
1-10	Card 7	x_p, define for AOPT=1.0	E10.0
11-20		y_p, define for AOPT=1.0	E10.0
21-30		z_p, define for AOPT=1.0	E10.0
1-10	Card 7	a_1, efine for AOPT=2.0	E10.0
11-20		a_2, define for AOPT=2.0	E10.0
21-30		a_3, define for AOPT=2.0	E10.0
1-10	Card 7	v_1, define for AOPT=3.0	E10.0
11-20		v_2, define for AOPT=3.0	E10.0
21-30		v_3, define for AOPT=3.0	E10.0
1-10	Card 8	d_1, define for AOPT=2.0	E10.0
11-20		d_2, define for AOPT=2.0	E10.0
21-30		d_3, define for AOPT=2.0	E10.0
1-10	Card 8	Material angle beta (may be overridden on the element card)	

Material Type 22 (Composite Damage Model)

Columns		Quantity		Format
1-10	Card 3	E_a	longitudinal direction	E10.0
11-20		E_b	transverse direction	E10.0
21-30		E_c	normal direction	E10.0
31-40		K_f	bulk modulus of failed material	E10.0
1-10	Card 4	υ_{ba}		E10.0
11-20		υ_{ca}		E10.0
21-30		υ_{cb}		E10.0
1-10	Card 5	G_{ab}		E10.0
11-20		G_{bc}		E10.0
21-30		G_{ca}		E10.0
1-10	Card 6	Material axes option, AOPT EQ.0.0: locally orthotropic with material axes determined by element nodes n_1 , n_2 , and n_4 as shown in Figure 1. Cards 7 and 8 below are blank with this option. EQ.1.0: locally orthotropic with material axes determine by a point in space and the global location of the element center.Card 8 below is blank. EQ.2.0: globally orthotropic with material axes determined by vectors defined on Cards 7 and 8 EQ.3.0: applicable to shell elements only. This option determines locally orthotropic material axes by offsetting the material axes by an angle (Card 8) from a line in the plane of the shell determined by taking the cross product of the vector defined on Card 7 with the shell normal vector.		
11-20		Material axes change flag for brick elements EQ.1.0: default EQ.2.0: switch material axes a and b EQ.3.0: switch material axes a and c		E10.0

Columns		Quantity	Format
1-10	Card 7	x_p define for AOPT=1.0	E10.0
11-20		y_p define for AOPT=1.0	E10.0
21-30		z_p define for AOPT=1.0	E10.0
1-10	Card 7	a_1 define for AOPT=2.0	E10.0
11-20		a_2 define for AOPT=2.0	E10.0
21-30		a_3 define for AOPT=2.0	E10.0
1-10	Card 7	v_1 define for AOPT=3.0	E10.0
11-20		v_2 define for AOPT=3.0	E10.0
21-30		v_3 define for AOPT=3.0	E10.0
1-10	Card 8	d_1 define for AOPT=2.0	E10.0
11-20		d_2 define for AOPT=2.0	E10.0
21-30		d_3 define for AOPT=2.0	E10.0
31-40		S_C shear strength, ab plane	E10.0
41-50		x_t longitudinal tensile strength, a-axis	E10.0
51-60		y_t transverse tensile strength, b-axis	E10.0
61-70		y_c transverse compressive strength	E10.0
71-80		Nonlinear shear stress parameter	E10.0

Define the material angle for each of the through-the-thickness integration points. For shell elements this data must follow Card 11.

Columns	Quantity	Format
1-10	β_1, material angle at first integration point	E10.0
11-20	β_2, material angle at second integration point	E10.0
21-30	β_3, material angle at third integration point	E10.0
.	.	.
.	.	.
.	.	.
71-80	β_8 , material angle at eight integration point.	E10.0

Continue on additional cards until NIP points have been defined, where NIP is the number of thickness integration points specified on card 10 for shell elements.

Material Type 23 (Thermal Orthotropic Elastic with 12 Curves)

Columns	Quantity	Format
1-10	Number of points in material constant vs. temperature curves NUMPTS (1< NUMPTS<49)	E10.0
1-10	Card 4 Blank	E10.0
1-10	Card 5 Blank	E10.0
1-10	Card 6 Material axes option, AOPT EQ.0.0: locally orthotropic with material axes determined by element nodes n_1 , n_2 , and n_4 as shown in Figure 1. Cards 7 and 8 below are blank with this option. EQ.1.0: locally orthotropic with material axes determine by a point in space and the global location of the element center. Card 8 below is blank. EQ.2.0: globally orthotropic with material axes determined by vectors defined on Cards 7 and 8 EQ.3.0: applicable to shell elements only. This option determines locally orthotropic material axes by offsetting the material axes by an angle (Card 8) from a line in the plane of the shell determined by taking the cross product of the vector defined on Card 7 with the shell normal vector.	E10.0
1-10	Card 7 x_p define for AOPT=1.0	E10.0
11-20	y_p define for AOPT=1.0	E10.0
21-30	z_p define for AOPT=1.0	E10.0
1-10	Card 7 a_1 define for AOPT=2.0	E10.0
11-20	a_2 define for AOPT=2.0	E10.0
21-30	a_3 define for AOPT=2.0	E10.0
1-10	Card 7 v_1 define for AOPT=3.0	E10.0
11-20	v_2 define for AOPT=3.0	E10.0
21-30	v_3 define for AOPT=3.0	E10.0
1-10	Card 8 d_1 define for AOPT=2.0	E10.0
11-20	d_2 define for AOPT=2.0	E10.0
21-31	d_3 define for AOPT=2.0	E10.0

Define the following card sets for each of the 12 orthotropic constants followed by the list of corresponding temperatures using the format (8E10.0). For shell elements, this data must follow cards 10 and 11.

Columns	Quantity	Format
1-10	E_a at temperature T_1	E10.0
11-20	E_a at temperature T_2	E10.0
.	.	.
.	.	.
.	.	.
71-80	E_a at temperature T_8	E10.0

Continue on additional cards until NUMPTS points have been defined. Definitions for variables, E_b , E_c , υ_{ba} , υ_{ba} , υ_{ca} , υ_{cb} , α_a , α_b , α_c , G_{ab} , G_{bc} , G_{ca} , and T (the list of temperatures) follow.

For shell elements only, define the material angle for each through the thickness integration point.

Columns	Quantity	Format
1-10	β_1 material angle at first integration point	E10.0
11-20	β_2 material angle at second integration point	E10.0
21-30	β_3 material angle at third integration point	E10.0
.	.	.
.	.	.
.	.	.
71-80	β_8 material angle at eighth integration point	E10.0

For shell elements, continue on additional cards as necessary until NIP points have been defined, where NIP is the number of thickness integration points specified on Card 10.

Material Type 24 (Piecewise Linear Isotropic Plasticity)

Columns		Quantity	Format
1-10	Card 3	Young's modulus	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Yield stress	E10.0
1-10	Card 6	Tangent modulus, ignored if the stress-strain curve is defined below	E10.0
11-20		Plastic strain at failure	E10.0
21-30		Time step size for automatic element deletion for strain rate effects	E10.0
31-40		Load curve number to scale yield stress to account	E10.0
1-80	Card 7	Effective plastic strain values (define up to 8 points)	E10.0
1-80	Card 8	Corresponding yield stress values	E10.0

Material Type 25 (Inviscid Two Invariant Geologic Cap Model)

This model is not vectorized.

Columns		Quantity	Format
1-10	Card 3	Bulk modulus	E10.0
11-20		Shear modulus	E10.0
1-10	Card 4	Alpha	E10.0
11-20		Theta	E10.0
21-30		Gamma	E10.0
31-40		Beta	E10.0
41-50		R	E10.0
1-10	Card 5	D, hardening law coefficient	E10.0
11-20		W, hardening law coefficient	E10.0
21-30		X_0, hardening law coefficient	E10.0
31-40		$\bar{c}$, kinematic hardening parameter	
41-50		N, kinematic hardening parameter	
1-10	Card 6	NPLOT = 1 κ	E10.0
		2 X	
		3 ε_V^p	
		4 J_1	
		5 $\sqrt{J_2}$	
		6 $\sqrt{J_2}_L$	
		7 $\sqrt{J_2}_{tr}$	
		8 MTYPE	
		9 Number of iterations	

Columns		Quantity	Format
1-10	Card 7	LTYPE = 1 Soil/Concrete (Cap Contracts)	E10.0
		= 2 Rock (Cap doesn't contract)	
11-20		IVEC (= 0 Vectorized, = 1 Iterative)	
1-10	Card 8	Tension Cut Off (T)	E10.0
		Note: This must be negative due to convection.	

NPLOT allows one to specify which variable will be stored in the TAURUS plot database, and plotted as the component "effective plastic strain".

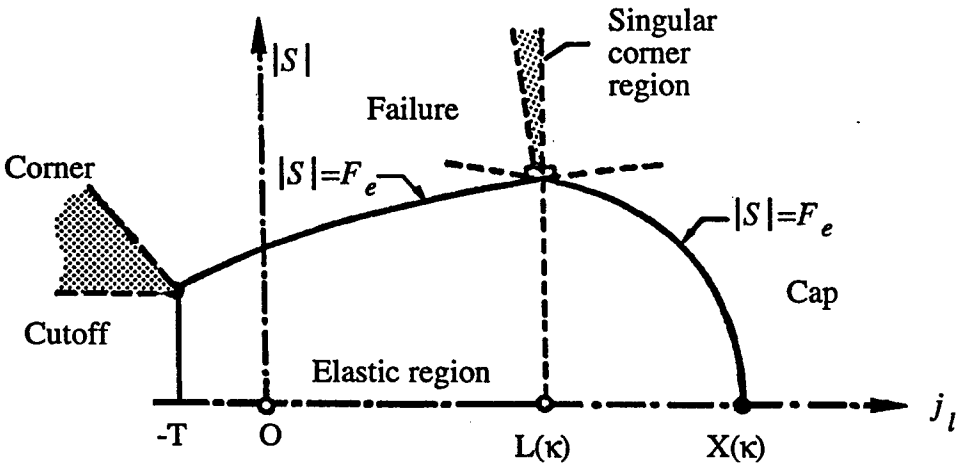


Figure 2-5. The yield surface of the two-invariant cap model in pressure/J_2-deviator space. $f_1 = 0$, $f_2 = 0$, and $f_3 = 0$, denote the failure envelope, the hardening cap surface, and the tension cut-off surface, respectively.

The shaded area is the "compressive corner regions".

$$f_1(\underset{\sim}{\sigma}) := \|\underset{\sim}{s}\| - F_e(J_1) \qquad \text{for} \quad -T \le J_1 < \kappa$$

$$f_2(\underset{\sim}{\sigma}, \kappa) := \|\underset{\sim}{s}\| - F_c(J_1, \kappa) \qquad \text{for} \quad \kappa \le J_1 < X(\kappa)$$

$$f_3(\underset{\sim}{\sigma}) := -T - J_1 \qquad \text{for} \quad -T \le J_1 < (\kappa) \quad ,$$

where $J_1 := tr\ \underset{\sim}{\sigma}$, $\|\underset{\sim}{s}\| := \sqrt{\underset{\sim}{s} : \underset{\sim}{s}}$, with $\underset{\sim}{s} := \underset{\sim}{\sigma} - \frac{1}{3}(tr\ \underset{\sim}{\sigma})\ \underset{\sim}{1}$.

In addition, T > 0 is an material constant refereed to as the tension cutoff. Note that the following standard conventions in soil mechanics, we have assumed compression and compaction positive. Functional forms for F_e and F_c used in DYNA3D are

$$F_e(J_1) := \left[\alpha - \lambda \exp(-\beta J_1) + \theta J_1\right] \tag{2.34}$$

$$F_c(J_1, \kappa) := \sqrt{F_e^{\,2}(\kappa) - \frac{[J_1 - \kappa]^2}{R^2}}, \tag{2.35}$$

where $\alpha > 0$, $\lambda > 0$, $\beta > 0$, $\theta > 0$, and $R > 0$ are material parameters. In addition, $X(\kappa)$ is a function of the hardening parameter κ defined as

$$X(\kappa) := \kappa + R\ F_e(\kappa) \quad . \tag{2.36}$$

$$\dot{\kappa} = \begin{cases} 0 & \text{if } tr\ \dot{\varepsilon}^p < 0,\ J_1 = \kappa \text{ and } \dot{f}_1 = \dot{f}_2 = 0 \\ \max\left[h'(\kappa)\, tr\ \dot{\varepsilon}^p\ ;\ \frac{\frac{d|s|}{dt}}{F_e(\kappa)}\right] & \text{if } J_1 = \kappa,\ \dot{f}_1 = 0, \text{ and } \dot{f}_2 < 0 \\ h'(\kappa)\, tr\ \dot{\varepsilon}^p & \text{otherwise} \end{cases}$$

$$\bar{h}(\kappa) := W\ \{1 - \exp[-D\ (X(\kappa) - X_o)]\} \tag{2.37}$$

Material Type 26 (Metallic Honeycomb)

Columns		Quantity	Format
1-10	Card 3	Young's modulus (for honeycomb material), E	E10.0
11-20		Poisson's ratio (for honeycomb material), ν	E10.0
21-30		Yield stress for fully compacted honeycomb (eg. to Honeycomb material), σ_y	E10.0
31-40		LCA, load curve number for sigma-aa versus either relative volume or volumetric strain (See Figure 6.)	E10.0
41-50		LCB, load curve number for sigma-bb versus either relative volume or volumetric strain. (default: LCB=LCA)	E10.0
51-60		LCC, load curve number for sigma-cc versus either relative volume or volumetric strain. (default: LCC=LCA)	E10.0
61-70		LCS, load curve number for shear stress versus either relative volume or volumetric strain. (default LCS=LCA). Each component of shear stress may have its own load curve via Card 5 input.	E10.0
71-80		Relative volume at which the honeycomb is fully compacted, V_f	E10.0
	Card 4	The following honeycomb parameters must be defined for there are no defaults.	
1-10		Elastic modulus E_{aau} in uncompressed configuration	E10.0
11-20		Elastic modulus E_{bbu} in uncompressed configuration	E10.0
21-30		Elastic modulus E_{ccu} in uncompressed configuration	E10.0
31-40		Elastic shear modulus G_{aau} in uncompressed configuration	E10.0
41-50		Elastic shear modulus G_{bcu} in uncompressed configuration	E10.0
51-60		Elastic shear modulus G_{cau} in uncompressed configuration	E10.0
1-10	Card 5	LCAB, load curve number for sigma-ab versus either relative volume or volumetric strain (default: LCAB=LCS)	E10.0

Columns		Quantity	Format
11-20		LCBC, load curve number for sigma-bc versus either relative volume or volumetric strain. (default: LCBC=LCS)	E10.0
21-30		LCCA, load curve number for sigma-ca versus either relative volume or volumetric strain. (default: LCCA=LCS)	E10.0
31-40		LCSR, optional load curve number for strainrate effects	E10.0
1-10	Card 6	Material axes option, AOPT EQ.0.0: locally orthotropic with material axes determined by element nodes as shown in Figure 1. Cards 7 and 8 are blank with this option. EQ.1.0: locally orthotropic with material axes determined by a point in space and the global location of the element center. Card 8 below is blank. EQ.2.0: globally orthotropic with material axes determined by vectors defined on Cards 7 and 8	E10.0
1-10	Card 7	x_p, define for AOPT = 1.0	E10.0
11-20		y_p, define for AOPT = 1.0	E10.0
21-30		z_p, define for AOPT = 1.0	E10.0
1-10	Card 7	a_1, define for AOPT = 2.0	E10.0
11-20		a_2, define for AOPT = 2.0	E10.0
21-30		a_3, define for AOPT = 2.0	E10.0
1-10	Card 8	d_1, define for AOPT = 2.0	E10.0
11-20		d_2, define for AOPT = 2.0	E10.0
21-30		d_3, define for AOPT = 2.0	E10.0

The behavior before compaction is orthotropic where the components of the stress tensor are uncoupled, i.e., an a component of strain will generate resistance in the local *a*-direction with no coupling to the local *b* and *c* directions. The elastic modulii vary from their initial values to the fully compacted values linearly with the relative volume:

$$E_{aa} = E_{aau} + \beta (E - E_{aau})$$

$$E_{bb} = E_{bbu} + \beta (E - E_{bbu})$$

$$E_{cc} = E_{ccu} + \beta (E - E_{ccu})$$

$$G_{ab} = G_{abu} + \beta (G - G_{abu})$$

$$G_{bc} = G_{bcu} + \beta (G - G_{bcu})$$

$$G_{ca} = G_{cau} + \beta (G - G_{cau})$$

where

$$\beta = \max\left[\min\left(\frac{1-V}{1-V_f}, 1\right), 0\right] \tag{2.38}$$

and G is the elastic shear modulus for the fully compacted honeycomb material

$$G = \frac{E}{2(1+\nu)} \tag{2.39}$$

The relative volume, V, is defined as the ratio of the current volume over the initial volume, and typically, V=1 at the beginning of a calculation. The two bulk viscosity coefficients on the first card in columns 46-65 of Card 1 should be set to very small numbers to prevent the development of spurious pressure that may lead to undesirable and confusing results.

The load curves define the magnitude of the average stress as the material changes density (relative volume). Each curve related to this model must have the same number of points and the same abscissa values. There are two ways to define these curves, a.) as a function of relative volume (V) or b.) as a function of volumetric strain defined as:

$$\varepsilon_v = 1 - V \tag{2.40}$$

In the former, the first value in the curve should correspond to a value of relative volume slightly less than the fully compacted value. In the latter, the first value in the curve should be less than or equal to zero corresponding to tension and increase to full compaction. Care should be taken when defining the curves so the extrapolated values do not lead to negative yield stresses.

At the beginning of the stress update we transform each elements stresses and strain rates into the local element coordinate system. For the uncompacted material, the trial stress components are updated using the elastic interpolated modulii according to:

$$\begin{aligned}
\sigma_{aa}^{n+1\,trial} &= \sigma_{aa}^{n} + E_{aa}\Delta\varepsilon_{aa} \\
\sigma_{bb}^{n+1\,trial} &= \sigma_{bb}^{n} + E_{bb}\Delta\varepsilon_{bb} \\
\sigma_{cc}^{n+1\,trial} &= \sigma_{cc}^{n} + E_{cc}\Delta\varepsilon_{cc} \\
\sigma_{ab}^{n+1\,trial} &= \sigma_{ab}^{n} + 2G_{ab}\Delta\varepsilon_{ab} \\
\sigma_{bc}^{n+1\,trial} &= \sigma_{bc}^{n} + 2G_{bc}\Delta\varepsilon_{bc} \\
\sigma_{ca}^{n+1\,trial} &= \sigma_{ca}^{n} + 2G_{ca}\Delta\varepsilon_{ca}
\end{aligned} \tag{2.41}$$

We then independently check each component of the updated stresses to ensure that they do not exceed the permissible values determined from the load curves, e.g., if

$$\left|\sigma_{ij}^{n+1\,trial}\right| > \lambda\sigma_{ij}(V) \quad then$$

$$\sigma_{ij}^{n+1} = \sigma_{ij}(V)\frac{\lambda\sigma_{ij}^{n+1\,trial}}{\left|\sigma_{ij}^{n+1\,trial}\right|} \tag{2.42}$$

On Card 3 $\sigma_{ij}(V)$ is defined in the load curve specified in columns 31-40 for the *aa* stress component, 41-50 for the *bb* component, 51-60 for the *cc* component , and 61-70 for the *ab, bc, cb* shear stress components. The parameter λ is either unity or a value taken from the load curve number, LCSR, that defines λ as a function of strainrate. Strainrate is defined here as the Euclidean norm of the deviatoric strainrate tensor.

For fully compacted material we assume that the material behavior is elastic-perfectly plastic and updated the stress components according to:

$$s_{ij}^{trial} = s_{ij}^{n} + 2G\Delta\varepsilon_{ij}^{dev\;\,n+\frac{1}{2}} \tag{2.43}$$

where the deviatoric strain increment is defined as

$$\Delta\varepsilon_{ij}^{dev} = \Delta\varepsilon_{ij} - \frac{1}{3}\Delta\varepsilon_{kk}\delta_{ij} \tag{2.44}$$

We now check to see if the yield stress for the fully compacted material is exceeded by comparing

$$s_{eff}^{trial} = \left(\frac{3}{2}s_{ij}^{trial}s_{ij}^{trial}\right)^{\frac{1}{2}} \tag{2.45}$$

the effective trial stress to the yield stress, σ_y (Card 3, field 21-30). If the effective trial stress exceeds the yield stress we simply scale back the stress components to the yield surface

$$s_{ij}^{n+1} = \frac{\sigma_y}{s_{eff}^{trial}}s_{ij}^{trial} \tag{2.46}$$

We can now update the pressure using the elastic bulk modulus, K

$$p^{n+1} = p^n - K\Delta\varepsilon_{kk}^{n+\frac{1}{2}}$$

$$K = \frac{E}{3(1-2\nu)} \tag{2.47}$$

and obtain the final value for the Cauchy stress

$$\sigma_{ij}^{n+1} = s_{ij}^{n+1} - p^{n+1}\delta_{ij} \tag{2.48}$$

After completing the stress update we transform the stresses back to the global configuration.

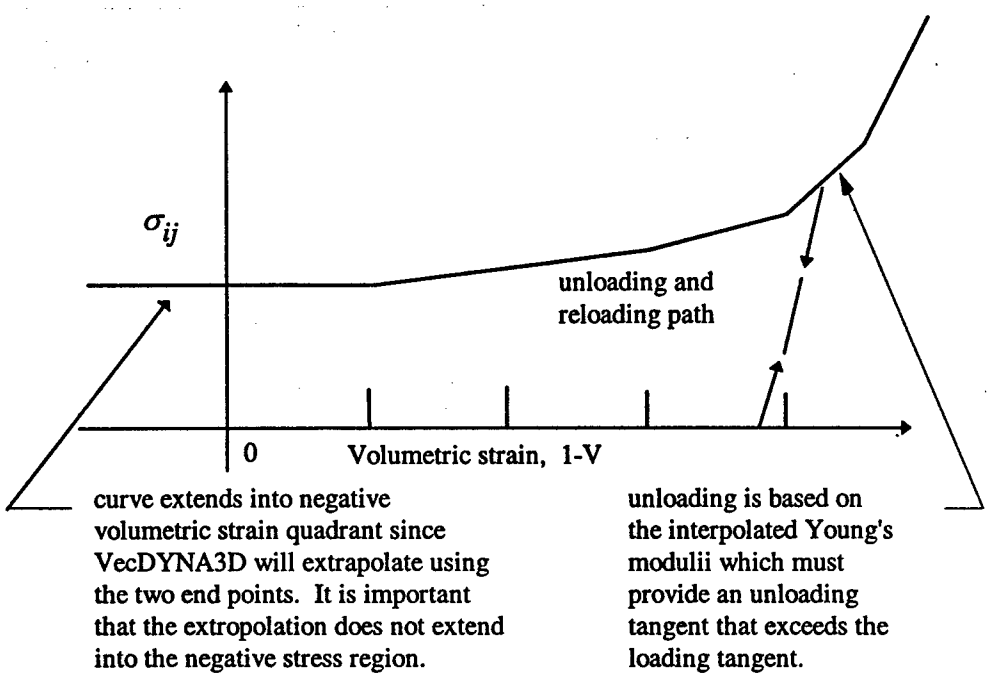


Figure 2-6. Stress quantity versus volumetric strain. Note that the "yield stress" at a volumetric strain of zero is nonzero. In the load curve definition the "time" value is the volumetric strain and the "function" value is the yield stress.

Material Type 27 (Compressible Mooney-Rivlin Rubber)

This material model maker provides an alternative to the Blatz-Ko rubber model.

Columns		Quantity	Format
1-10	Card 3	A	E10.0
11-20		B	E10.0
21-30		υ, Poisson's ratio	E10.0
	Card 4	Blank	
	.	.	
	.	.	
	.	.	
	Card 8	Blank	

The strain energy density function is defined as:

$$W = A(I-3) + B(II-3) + C(III^{-2} - 1) + D(III-1)^2$$

where $C = 0.5\,A + B$

$$D = \frac{A(5\upsilon - 2) + B(11\upsilon - 5)}{2(1 - 2\upsilon)}$$

υ = Poisson's ratio

$2(A+B) = G$ = shear modulus of linear elasticity

I, II, III are invariants of right Cauchy-Green Tensor $\underline{C}$

Material Type 28 (Resultant Plasticity)

This model is available for the Belytschko-Schwer beam and the Belytschko-Tsay shell, and is still under development. For beams, the treatment is elastic-perfectly plastic, but for shell elements isotropic hardening is approximately modeled.

Columns	Quantity		Format
1-10	Card 3	Young's modulus	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Yield stress	E10.0
1-10	Card 6	Hardening modulus, E_t (shells only)	E10.0
1-10	Card 7	Blank	
1-10	Card 8	Blank	

Material Type 30 (Closed-Form Update Shell Plasticity)

This model implements a closed form solution for the plane stress constitutive update under conditions of perfect plasticity or kinematic hardening for a bilinear von Mises model. The implementation is described in (Whirley, Hallquist and Goudreau).

Columns	Quantity		Format
1-10	Card 3	Young's modulus	E10.0
1-10	Card 4	Poisson's ratio	E10.0
1-10	Card 5	Yield stress	E10.0
1-10	Card 6	Hardening modulus, E_t	E10.0
	Card 7	Blank	
	Card 8	Blank	

Material Type 31 (Frazer-Nash Rubber Model)

This model implements a hyperelastic constitutive law described in (Kenchington).

Columns		Quantity	Format
1-10	Card 3	G001	E10.0
11-20		G010	E10.0
21-30		G020	E10.0
31-40		G100	E10.0
41-50		G101	E10.0
1-10	Card 4	G110	E10.0
11-20		G200	E10.0
21-30		G210	E10.0
31-40		G300	E10.0
41-50		G400	E10.0
1-10	Card 5	Exit or continue option	E10.0
		= 0.0 stop if strain limits are exceeded	
		= 0.0 continue if strain limits are exceeded	
1-10	Card 6	Maximum strain limit	E10.0
11-20		Minimum strain limit	E10.0
	Card 7	Blank	
	Card 8	Blank	

Define equation-of-state cards only if (7 < MT < 12 or MT = 17)

Material Types 41-50 (User Defined Material Models)

Define the number of fields specified in the control section using only as many cards as needed with eight parameters per card with format 8E10.0 The locations of the bulk modulus, shear modulus, and the orientation set must be consistent with the control card defined for the material type.

Columns	Quantity	Format
1-10	First material parameter	E10.0
11-20	Second material parameter	E10.0
21-30	Third material parameter	E10.0
31-40	Fourth material parameter	E10.0

The orientation information begins at the specified address and contains the following information.in the order given.below.

1. Material axes option, AOPT
   - EQ.0.0: locally orthotropic with material axes determined by element nodes n_1, n_2, and n_4 as shown in Figure 1. Cards 7 and 8 below are blank with this option.
   - EQ.1.0: locally orthotropic with material axes determine by a point in space and the global location of the element center.Card 8 below is blank.
   - EQ.2.0: globally orthotropic with material axes determined by vectors defined on Cards 7 and 8
   - EQ.3.0: applicable to shell elements only. This option determines locally orthotropic material axes by offsetting the material axes by an angle (Card 12) from a line in the plane of the shell determined by taking the cross product of the vector defined as 3-5 with the shell normal vector.

2. Material axes change flag for brick elements
   - EQ.1.0: default
   - EQ.2.0: switch material axes a and b
   - EQ.3.0: switch material axes a and c

3. x_p define for AOPT=1.0

   a_1 define for AOPT=2.0

   v_1 define for AOPT=3.0

Columns	Quantity	Format
4.	y_p define for AOPT=1.0	
	a_2 define for AOPT=2.0	
	v_2 define for AOPT=3.0	
5.	z_p define for AOPT=1.0	
	a_3 define for AOPT=2.0	
	v_3 define for AOPT=3.0	
6.	d_1 define for AOPT=2.0	
7.	d_2 define for AOPT=2.0	
8.	d_3 define for AOPT=2.0	

For shell elements define the material angle for each of the through-the-thickness integration points. This data is defined if and only if the orientation option is active and follows Card 11.

Columns	Quantity	Format
1-10	β_1, material angle at first integration point	E10.0
11-20	β_2, material angle at second integration point	E10.0
21-30	β_3, material angle at third integration point	E10.0
.	.	.
.	.	.
.	.	.
71-80	β_8 , material angle at eight integration point.	E10.0

Continue on additional cards until NIP points have been defined, where NIP is the number of thickness integration points specified on card 10 for shell elements.

Equation-of-State Form 1 (Linear Polynomial)

Columns		Quantity	Format
1-10	Card 10	C_0	E10.0
11-20		C_1	E10.0
21-30		C_2	E10.0
31-40		C_3	E10.0
41-50		C_4	E10.0
51-60		C_5	E10.0
61-70		C_6	E10.0
71-80		E_0, initial internal energy	E10.0
1-10	Card 11	V_0, initial relative volume	E10.0

The linear polynomial equation-of-state is linear in internal energy. The pressure is given by:

$$P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + \left(C_4 + C_5\mu + C_6\mu^2\right) E \tag{2.49}$$

where terms $C_2\mu^2$ and $C_6\mu^2$ are set to zero if $\mu < 0$, $\mu = \frac{\rho}{\rho_0} - 1$, and $\frac{\rho}{\rho_0}$ is the ratio of current density to initial density. An acoustic fluid is recovered if $C_1 = \rho_0 c^2$ and all other constants are zero.

Equation-of-State Form 2 (JWL)

Columns		Quantity	Format
1-10	Card 10	A	E10.0
11-20		B	E10.0
21-30		R1	E10.0
31-40		R2	E10.0
41-50		ω	E10.0
51-60		E_0	E10.0
61-70		V_0	E10.0

The JWL equation-of-state defines the pressure as

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)e^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)e^{-R_2 V} + \frac{\omega E}{V}, \tag{2.50}$$

and is usually used for detonation products of high explosives.

Equation-of-State Form 3 (Sack "Tuesday")

Columns		Quantity	Format
1-10	Card 10	A_1	E10.0
11-20		A_2	E10.0
21-30		A_3	E10.0
31-40		B_1	E10.0
41-50		B_2	E10.0
51-60		E_0, initial internal energy	E10.0
61-70		V_0, initial relative volume	E10.0

The Sack equation-of-state defines pressure as

$$p = \frac{A_3}{V^{A_1}} e^{-A_2 V} \left(1 - \frac{B_1}{V}\right) + \frac{B_2}{V} E \tag{2.51}$$

and is used for detonation products of high explosives.

Equation-of-State Form 4 (Gruneisen)

Columns		Quantity	Format
1-10	Card 10	C	E10.0
11-20		S_1	E10.0
21-30		S_2	E10.0
31-40		S_3	E10.0
41-50		γ_0	E10.0
51-60		a	E10.0
61-70		E_0, initial internal energy	E10.0
71-80		V_0, initial relative volume	E10.0

The Gruneisen equation-of-state with cubic shock velocity-particle velocity defines pressure for compressed materials as

$$p = \frac{\rho_0 C^2 \mu \left[1 + \left(1 - \frac{\gamma_0}{2}\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1 - (S_1 - 1)\mu - S_2 \frac{\mu^2}{\mu+1} S_3 \frac{\mu^3}{(\mu+1)}\right]^2} + (\gamma_0 + a\mu)E. \tag{2.52}$$

and for expanded materials as

$$p = \rho_0 C^2 \mu + (\gamma_0 + a\mu)E. \tag{2.53}$$

where C is the intercept of the u_s-u_p curve; S_1, S_2, and S_3 are the coefficients of the slope of the u_s-u_p curve; γ_0 is the Grunesian gamma; a is the first order volume correction to γ_0 and $\mu = \frac{\rho}{\rho_0} - 1$

Equation-of-State Form 5 (Ratio of Polynomials)

Columns	Quantity		Format
1-16	Card 10	A10	E16.0
17-32		A11	E16.0
33-48		A12	E16.0
49-64		A13	E16.0
1-16	Card 11	A20	E16.0
17-32		A21	E16.0
33-48		A22	E16.0
49-64		A23	E16.0
1-16	Card 12	A30	E16.0
17-32		A31	E16.0
33-48		A32	E16.0
49-64		A33	E16.0
1-16	Card 13	A40	E16.0
17-32		A41	E16.0
33-48		A42	E16.0
49-64		A43	E16.0
1-16	Card 14	A50	E16.0
17-32		A51	E16.0
33-48		A52	E16.0
49-64		A53	E16.0
1-16	Card 15	A60	E16.0
17-32		A61	E16.0
33-48		A62	E16.0
49-64		A63	E16.0

Columns		Quantity	Format
1-16	Card 16	A70	E16.0
17-32		A71	E16.0
33-48		A72	E16.0
49-64		A73	E16.0
1-16	Card 18	α	E16.0
17-32		β	E16.0
33-48		A14	E16.0
49-64		A24	E16.0
1-16	Card 19	E_0, initial internal energy	E16.0
17-32		V_0, initial relative volume	E16.0

The ratio of polynomials equation-of-state defines the pressure as

$$p = \frac{F_1 + F_2 E + F_3 E^2 + F_4 E^2}{F_5 + F_6 E + F_7 E^2} (1 + \alpha\mu) \tag{2.54}$$

where

$$F_i = \sum_{j=0}^{n} A_{ij}\, \mu^j \qquad n = 4 \text{ if } i < 3$$

$$\mu = \frac{\rho}{\rho_0} - 1 \qquad n = 3 \text{ if } i \geq 3$$

In expanded elements F_1 is replaced by $F_1' = F_1 + \beta\mu^2$. By setting coefficient A10 = 1.0, the delta-phase pressure modeling for this material will be initiated. The code will reset it to 0.0 after setting flags.

Equation-of-State Form 6 (Linear Polynomial with Energy Leak)

Columns		Quantity	Format
1-10	Card 10	C_0	E10.0
11-20		C_1	E10.0
21-30		C_2	E10.0
31-40		C_3	E10.0
41-50		C_4	E10.0
51-60		C_5	E10.0
61-70		C_6	E10.0
71-80		E_0, initial internal energy	E10.0
1-10	Card 11	V_0, initial relative volume	E10.0
11-20		CN, number of time history curve that gives energy deposition rate.	E10.0

Equation-of-State Form 7 (Ignition and Growth of Reaction in HE)

Columns		Quantity	Format
1-10	Card 10	A_p	E10.0
11-20		B_p	E10.0
21-30		$R1_p$	E10.0
31-40		$R2_p$	E10.0
41-50		G, second ignition coefficient	E10.0
1-10	Card 11	$\omega_p c_p$	E10.0
11-20		A_e	E10.0
21-30		B_e	E10.0
31-40		$\omega_e c_e$	E10.0
41-50		$R1_e$	E10.0
1-10	Card 12	$R2_e$	E10.0
11-20		FCRIT, critical fraction reacted (usually = 1.0)	E10.0
21-30		I, first ignition coefficient	E10.0
31-40		H, growth coefficient	E10.0
41-50		z, pressure exponent	E10.0
1-10	Card 13	x	E10.0
11-20		y	E10.0
21-30		c_p, heat capacity of reaction products	E10.0
31-40		c_e, heat capacity of unreacted HE	E10.0
1-10	Card 14	m (generally = 0)	E10.0
11-20		E_0, initial energy of HE per unit volume	E10.0
21-30		T_0, initial temperature (°K)	E10.0
	Card 15	Blank	

A JWL equation-of-state defines the pressure in the unreacted HE as

$$P_e = A_e\left(1-\frac{\omega_e}{R1_eV_e}\right)e^{-R1_eV_e} + B_e\left(1-\frac{\omega_e}{R2_eV_e}\right)e^{-R2_eV_e} + \frac{\omega E_e}{V_e} \tag{2.55}$$

where V_e is the relative volume, E_e is the internal energy, and the constants A_e, B_e, ω_e, $R1_e$, and $R2_e$ are inputs.

Similarly, the pressure in the reaction products is defined by another JWL form

$$P_p = A_p\left(1-\frac{\omega_p}{R1_pV_p}\right)e^{-R1_pV_p} + B_e\left(1-\frac{\omega_p}{R2_pV_p}\right)e^{-R2_pV_p} + \frac{\omega E_p}{V_p} \tag{2.56}$$

The mixture of unreacted explosive and reaction products is defined by the fraction reacted F (F = 0 → no reaction, F = 1 → complete conversion from explosive to products). The pressures and temperature are assumed to be in equilibrium and the volumes are assumed to be additive.

$$V = (1-F)V_e + FV_p \tag{2.57}$$

The rate of reaction for Material Type 13 is

$$\frac{\partial F}{\partial t} = I(FCRIT-F)^y\left(V_e^{-1}-1\right)^3\left[1+G\left(V_e^{-1}-1\right)\right] + H(1-F)^y F^x P^z\left(V_p^{-1}-1\right)m \tag{2.58}$$

where I, G, H, x, y, z, and m (generally m=0) are input constants.

The JWL equations of state and the reaction rates have been fitted to one- and two-dimensional shock initiation and detonation data for four explosives: PBX-9404, RX-03-BB, PETN, and cast TNT. The details of the calculational method are described by (Cochran and Chan). The detailed one-dimensional calculations and parameters for the four explosives are given by (Lee and Tarver).

Equation-of-State Form 8 (Tabulated-Compaction)

Columns		Quantity	Format
1-16	Card 10	ε_{V1} (ln V)	E16.0
17-32		ε_{V2}	E16.0
33-48		ε_{V3}	E16.0
49-64		ε_{V4}	E16.0
65-80		ε_{V5}	E16.0
1-16	Card 11	ε_{V6}	E16.0
17-32		ε_{V7}	E16.0
33-48		ε_{V8}	E16.0
49-64		ε_{V9}	E16.0
65-80		ε_{V10}	E16.0
1-16	Card 12	C_1	E16.0
17-32		C_2	E16.0
33-48		C_3	E16.0
49-64		C_4	E16.0
65-80		C_5	E16.0
1-16	Card 13	C_6	E16.0
17-32		C_7	E16.0
33-48		C_8	E16.0
49-64		C_9	E16.0
65-80		C_{10}	E16.0
1-16	Card 14	T_1	E16.0
17-32		T_2	E16.0
33-48		T_3	E16.0
49-64		T_4	E16.0
65-80		T_5	E16.0

Columns		Quantity	Format
1-16	Card 15	T_6	E16.0
17-32		T_7	E16.0
33-48		T_8	E16.0
49-64		T_9	E16.0
65-80		T_{10}	E16.0
1-16	Card 16	K_1	E16.0
17-32		K_2	E16.0
33-48		K_3	E16.0
49-64		K_4	E16.0
65-80		K_5	E16.0
1-16	Card 17	K_6	E16.0
17-32		K_7	E16.0
33-48		K_8	E16.0
49-64		K_9	E16.0
65-80		K_{10}	E16.0
1-16	Card 18	γ	E16.0
17-32		E_0, initial internal energy	E16.0
33-48		E_0, initial relative volume	E16.0

The tabulated compaction model is linear in internal energy. Pressure is defined by

$$p = C\left(\varepsilon_V\right) = gT\left(\varepsilon_V\right)E \tag{2.59}$$

in the loading phase. The volumetric strain, ε_V is given by the natural logarithm of the relative volume, Unloading occurs along the unloading bulk modulus to the pressure cutoff. Reloading always follows the unloading path to the point where unloading began, and continues on the loading path. See Figure 7. Up to 10 points and as few as 2 may be used when defining the tabulated functions, VecDYNA3D will extrapolate to find the pressure if necessary.

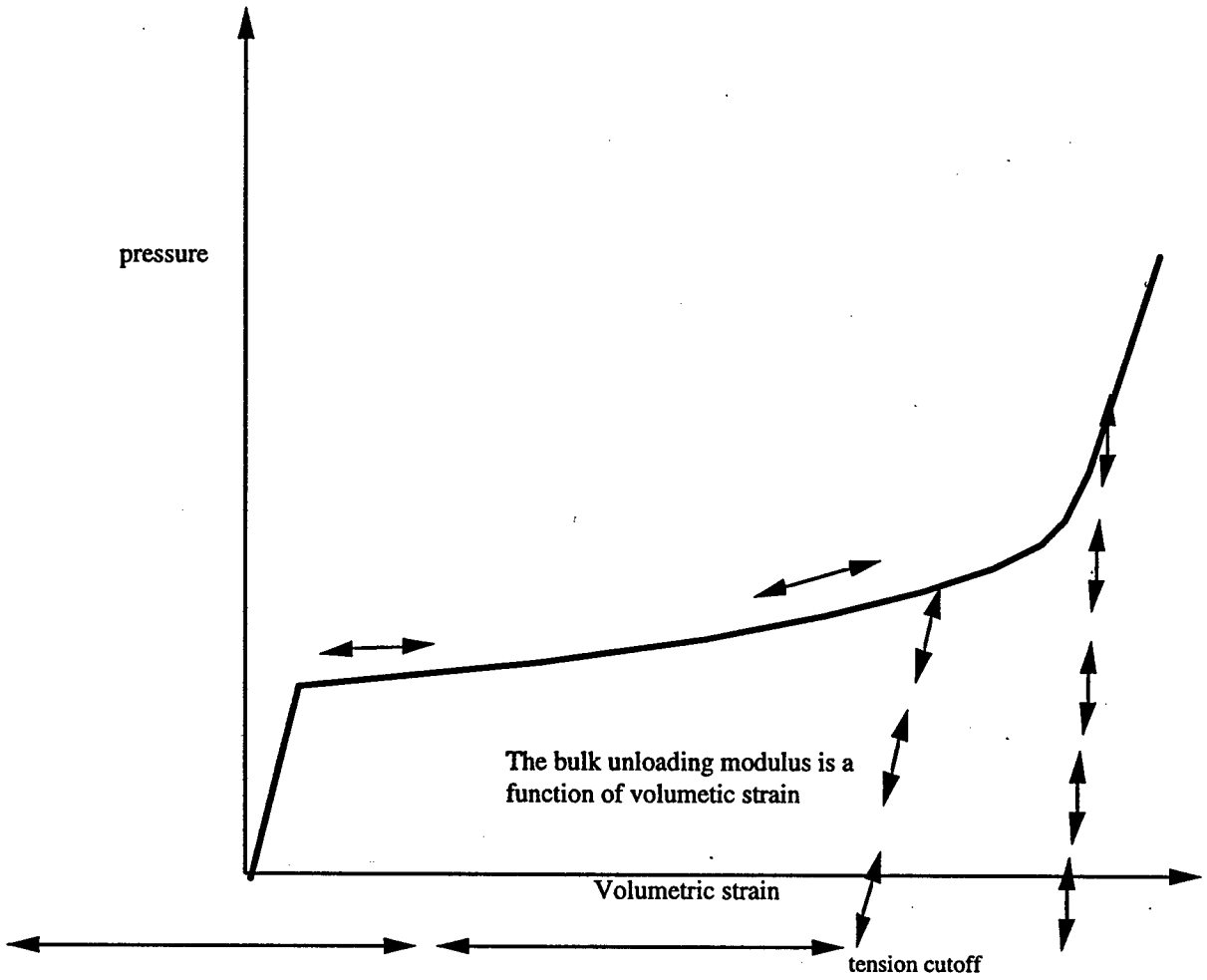


Figure 2-7. Pressure versus volumetric strain curve for equation-of-state Form 8 with compaction. In the compacted states the bulk unloading modulus depends on the peak volumetric strain.

Equation-of-State Form 9 (Tabulated)

Columns		Quantity	Format
1-16	Card 10	ε_{V1} (ln V)	E16.0
17-32		ε_{V3}	E16.0
33-48		ε_{V3}	E16.0
49-64		ε_{V4}	E16.0
65-80		ε_{V5}	E16.0
1-16	Card 11	ε_{V6}	E16.0
17-32		ε_{V7}	E16.0
33-48		ε_{V8}	E16.0
49-64		ε_{V9}	E16.0
65-80		ε_{V10}	E16.0
1-16	Card 12	C_1	E16.0
17-32		C_2	E16.0
33-48		C_3	E16.0
49-64		C_4	E16.0
65-80		C_5	E16.0
1-16	Card 13	C_6	E16.0
17-32		C_7	E16.0
33-48		C_8	E16.0
49-64		C_9	E16.0
65-80		C_{10}	E16.0
1-16	Card 14	T_1	E16.0
17-32		T_2	E16.0
33-48		T_3	E16.0
49-64		T_4	E16.0
65-80		T_5	E16.0

Columns		Quantity	Format
1-16	Card 15	T_6	E16.0
17-32		T_7	E16.0
33-48		T_8	E16.0
49-64		T_9	E16.0
65-80		T_{10}	E16.0
1-16	Card 16	γ	E16.0
17-32		E_0	E16.0
33-48		V_0	E16.0

The tabulated equation-of-state model is linear in internal energy. Pressure is defined by

$$P = C(\varepsilon_V) + \gamma T(\varepsilon_V)E \tag{2.60}$$

The volumetric strain, ε_V is given by the natural logarithm of the relative volume. Up to 10 points and as few as 2 may be used when defining the tabulated functions. VecDYNA3D will extrapolate to find the pressure if necessary.

Equation-of-State Form 11 (TENSOR Pore Collapse)

Card 1 (2I5,4E10.0)

Columns	Quantity	Format
1-5	Number of Virgin Loading Curve points (NLD)	15
6-10	Number of Completely Crushed Curve points (NCR)	15
11-20	Excess Compression required before any pores can collapse (μ_1)	E10.0
21-30	Excess Compression point where the Virgin Loading Curve and the Completely Crushed Curve intersect (μ_2)	E10.0
31-40	Initial Internal Energy	E10.0
41-50	Initial Excess Compression	E10.0

Virgin Loading Curve Definition

CARD 2 through NLD+1 (2E15.0)

Columns	Quantity	Format
1-15	Excess Compression	E15.0
16-30	Pressure	E15.0

Completely Crushed Curve Definition

CARD NLD+2 through NLD+NCR+1

Columns	Quantity	Format
1-15	Excess Compression	E15.0
16-30	Pressure	E15.0

The pore collapse model described in the TENSOR manual (Burton) is no longer valid and has been replaced by a much simpler method. This is due in part to the lack of experimental data required for the more complex model. It is desired to have a close approximation of the TENSOR model in the DYNA code to enable a quality link (Crawfis) between them. The TENSOR model defines two curves, the virgin loading curve and the completely crushed curve as shown in Figure 8. It also defines the excess compression point required for pore collapse to begin (μ_1), and the excess compression point required to completely crush the material (μ_2). From this data and the maximum excess compression the material has attained (μ_{max}), the pressure for any excess compression (μ) can be determined. Unloading occurs along the virgin loading curve until the excess compression surpasses μ_1. After that, the unloading follows a path between the completely crushed curve and the virgin loading curve. Reloading will follow this curve back up to the virgin loading curve. Once the excess compression exceeds μ_2, then all unloading will follow the completely crushed curve.

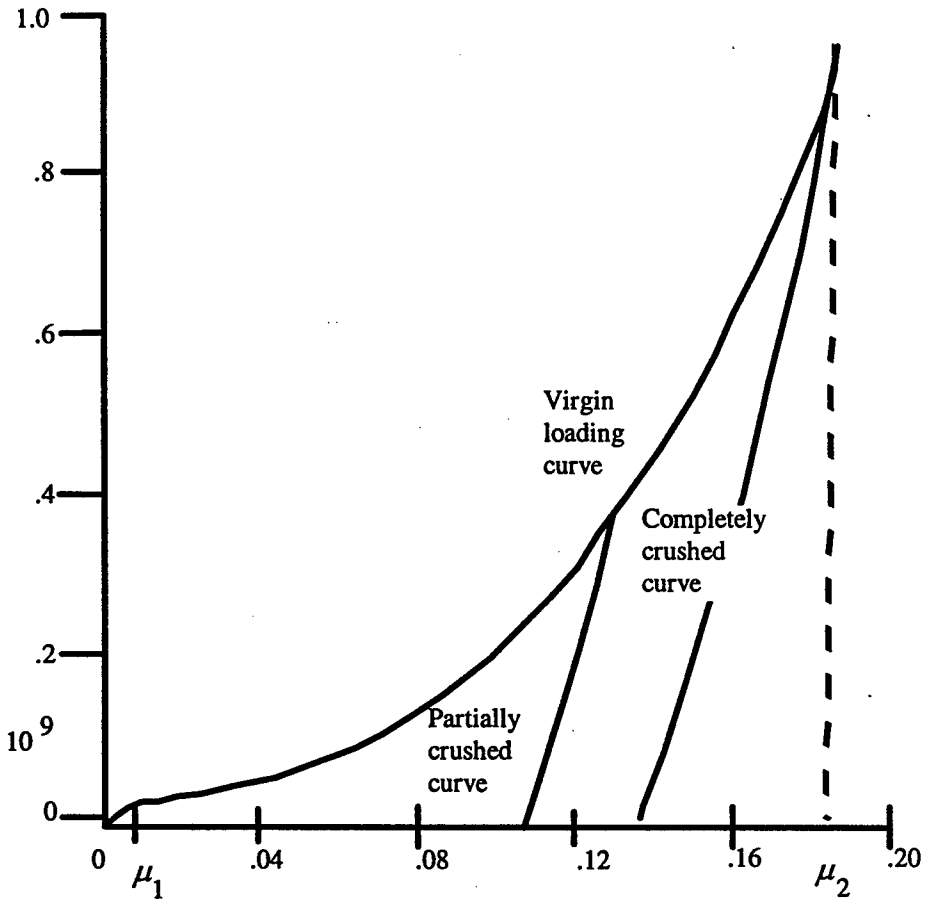


Figure 2-8. Pressure versus compaction curve.

For unloading between μ_1 and μ_2 a partially crushed curve is determined by the relationship:

$$p_{pc}(\mu) = p_{cc}\left(\frac{(1+\mu_B)(1+\mu)}{1+\mu_{\max}} - 1\right). \tag{2.61}$$

where

$$\mu_B = P_{cc}^{-1}(P_{\max}) \tag{2.62}$$

and the subscripts pc and cc refer to the partially crushed and completely crushed states, respectively. This is more readily understood in terms of the relative volume (V).

$$V = \frac{1}{1+\mu}$$

$$P_{pc}(V) = P_{cc}\left(\frac{V_B}{V_{\min}}V\right) \tag{2.63}$$

This representation suggest that for a fixed $V_{\min}\left(=\frac{1}{\mu_{\max}+1}\right)$ the partially crushed curve will separate linearly from the completely crushed curve as V increases to account for pore recovery in the material.

The bulk modulus K is determined to be the slope of the current curve times one plus the excess compression:

$$K = \frac{\partial P}{\partial \mu}(1+\mu) \tag{2.64}$$

The slope $\frac{\partial P}{\partial \mu}$ for the partially crushed curve is obtained by differentiation as:

$$\frac{\partial P}{\partial \mu} = \frac{\partial P_{cc}\left(\frac{(1+\mu_B)(1+\mu)}{(1\mu_{\max})}\right)(1+\mu_B)}{\partial \mu \qquad (1+\mu_{\max})} \tag{2.65}$$

Simplifying,

$$K = \frac{\partial P_{cc}(\mu_a)}{\partial \mu}(1+\mu_a) \tag{2.66}$$

where

$$\mu_a = \frac{(1 + \mu_B)(1 + \mu)}{(1 + \mu_{max})} - 1 \tag{2.67}$$

The bulk sound speed is determined from the slope of the completely crushed curve at the current pressure to avoid instabilities in the time step.

The virgin loading and completely crushed curves are modeled with monotonic cubic-splines. An optimized vector interpolation scheme is then used to evaluate the cubic-splines. The bulk modulus and sound speed are derived from a linear interpolation on the derivatives of the cubic-splines.

Cross Section Property Definition for Structural Elements

Define structural element cross section parameters if element class is non-zero:

Card 9 (12A6)

Columns	Quantity	Format
1-10	Cross section identification	126A

Cards 10 and 11

The following cards are defined for the beam and truss elements.

Cards 10 (3E10.0)

Columns	Quantity	Format
1-10	Shear factor, default = 1.0	E10.0
11-20	Quadrature rule for Hughes-Liu beam cross section EQ.1.0: truss element EQ.2.0: 2×2 Gauss quadrature (default beam) EQ.3.0: 3×3 Gauss quadrature EQ.4.0: 3×3 Lobatto quadrature EQ.5.0: 4×4 Gauss quadrature EQ. -N: User integration rule N	E10.0
21-30	Cross section type for Hughes-Liu beam (BCST) EQ.0.0: rectangular EQ.1.0: tubular EQ.2.0: arbitrary (user defined integration rule)	E10.0

For the Hughes-Liu beam, Card 11 is given as:

Card 11 (4E10.0)

Columns	Quantity	Format
1-10	Beam thickness (BCST=0.0, 2.0) or outer diameter (BCST = 1.0) in s direction at node n_1 (see Figure 9)	E10.0
11-20	Beam thickness (BCST=0.0, 2.0) or outer diameter (BCST = 1.0) in s direction at node n_2	E10.0
21-30	Beam thickness (BCST=0.0, 2.0) or inner diameter (BCST = 1.0) in t direction at node n_1	E10.0
31-40	Beam thickness (BCST=0.0, 2.0) or inner diameter (BCST = 1.0) in t direction at node n_2	E10.0
41-50	Location of reference surface normal to s axis EQ. 1.0: side at s=1 EQ. 0.0: center EQ. -1.0: side at s= -1.0	E10.0
51-60	Location of reference surface normal to t axis EQ. 1.0: side at t=1 EQ. 0.0: center EQ. -1.0: side at t= -1.0	E10.0

For the Belytschko-Schwer beam, Card 11 becomes:

Card 11 (5E10.0)

Columns	Quantity	Format
1-10	Cross-sectional area, A	E10.0
11-20	I_{ss}	E10.0
21-30	I_{tt}	E10.0
31-40	I_{rr}	E10.0
41-50	Shear area, A_s	E10.0

For the truss element, define the cross-sectional area, A, and leave columns 11- 80 blank.

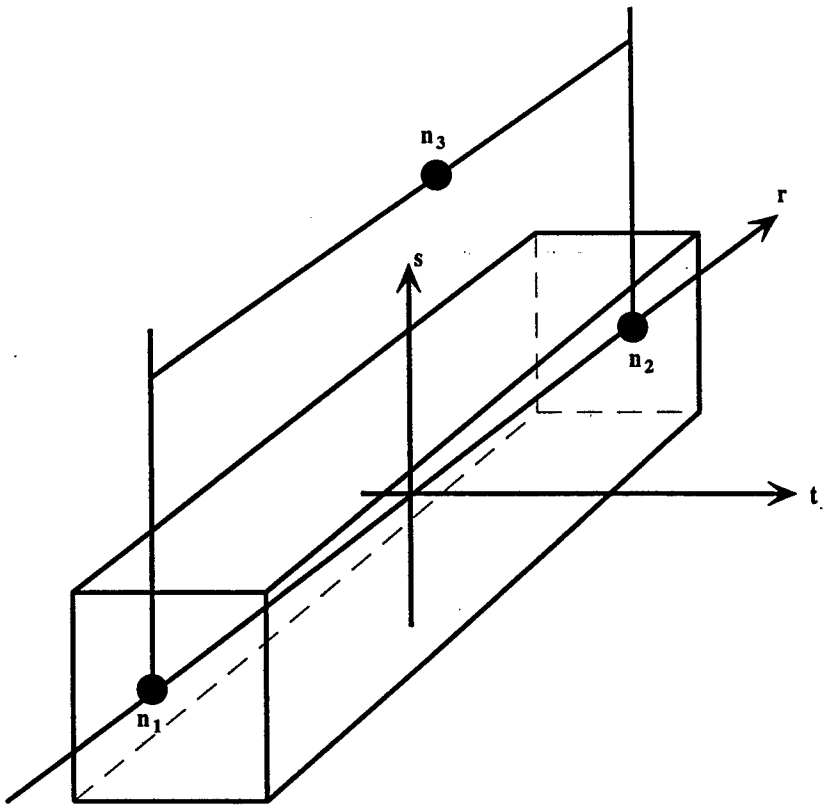


Figure 2-9. VecDYNA3D beam elements. Node n_3 determines the initial orientation.

Card 10 (4E10.0)

The following cards are defined for 4 node shell and membrane elements

Columns	Quantity	Format
1-10	Shear factor (default = 1.0)	E10.0
11-20	Number of through shell thickness integration points EQ.1: 1 point (membrane) EQ.2: 2 point EQ.3: 3 point EQ.4: 4 point EQ.5: 5 point GT.5: trapezoidal or user defined rule	E10.0
21-30	Printout option EQ.1: average resultants and fiber lengths EQ.2: resultants at plan points and fiber lengths EQ.3: resultants, stresses at all points, fiber lengths	E10.0
31-40	Quadrature rule LT.0.0: absolute value is specified rule number EQ.0.0: Gauss (up to five points are permitted) EQ.1.0: trapezoidal	E10.0

Card 11 (5E10.0)

Columns	Quantity	Format
1-10	Shell thickness at node n_1 (See Figure 10)	E10.0
11-20	Shell thickness at node n_2	E10.0
21-30	Shell thickness at node n_3	E10.0
31-40	Shell thickness at node n_4	E10.0
41-50	Location of reference surface (Hughes-Liu shell theory only) EQ.1.0: top surface EQ.0.0: midsurface (default for Hughes-Liu and mandatory for Belytschko-Tsay) EQ.-1.0: bottom surface	E10.0

The above thickness values are used if and only if the thickness values are zero on the element cards.

The location of the reference surface can be crucial whenever beams, shells, and solids are interconnected. Often it is desirable to have the beams and shells share a common reference surface. Whenever shells lie along interfaces, the reference surface should be on the contact surface. This option only applies to the Hughes-Liu shell theory with the shell normal update option set to -2.

The following cards are defined for the 8-node thick shell:

Card 10 (2E10.0)

Columns	Quantity	Format
1-10	Shear factor (default =1.0) E10.0	
11-20	Quadrature rule through shell thickness EQ.1.0: membrane EQ.2.0: 2 point Gauss quadrature EQ.3.0: 3 point Gauss quadrature EQ.4.0: 4 point Gauss quadrature EQ.5.0: 5 point Gauss quadrature	E10.0

Card 11 Blank

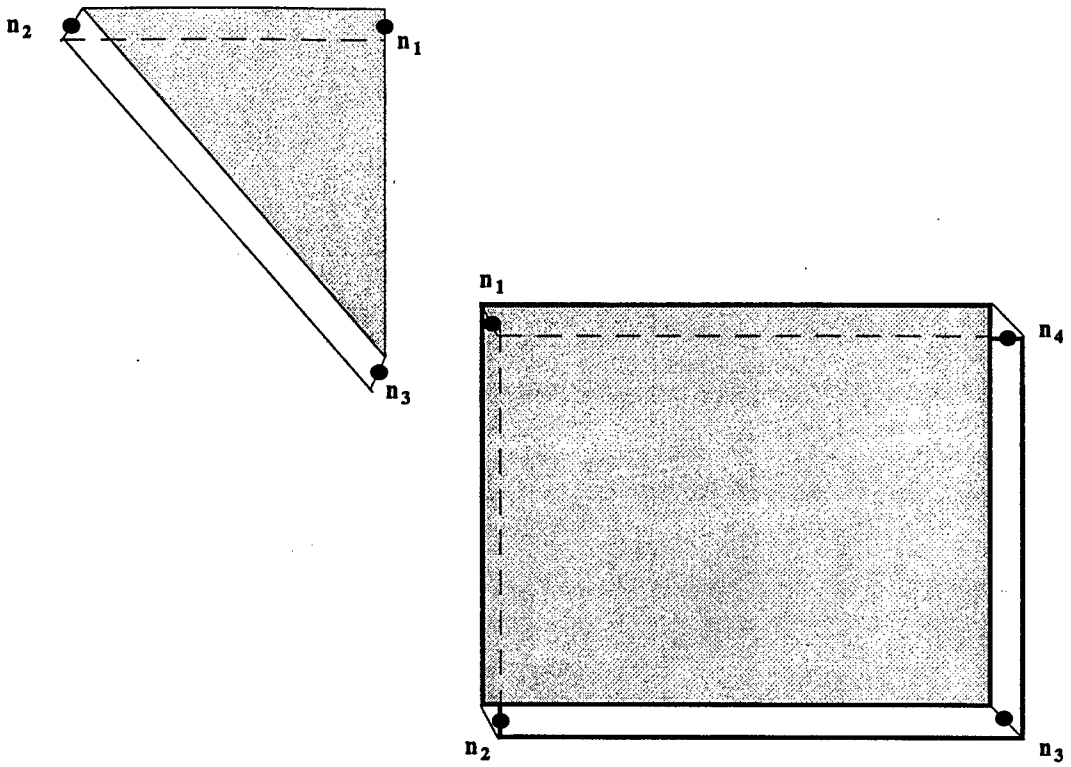


Figure 2-10. VecDYNA3D shell elements. Counterclockwise node numbering determines the top surface.

2.4 USER DEFINED INTEGRATION RULES FOR THE HUGHES-LIU BEAMS WITH AN ARBITRARY CROSS SECTION.

Define NUSBIR Card sets in this section.

Card 1 (15,E10.0)

Columns	Quantity	Format
1-15	Number of integration points, NIP (if ICST = 0)	15
6-10	Relative area of cross section, i.e., the actual cross-sectional area divided by the area defined by the product of the specified thickness in the s direction and the thickness in the t direction	E10.0
11-20	Standard cross-section type, ICST. If this is nonzero, then NIP and relative area defined above should be set to zero. Section library (Figure 11): EQ. 1: W-section EQ. 2: C-section EQ. 3: Angle section EQ. 4: T-section EQ. 5: Rectangular tubing EQ. 6: Z-section EQ. 7: Trapezoidal section EQ. 11: W-section rotated CW 90° EQ. 14: T-section rotated CW 90° EQ. 15: Rect-section rotated CW 90°	

Cards 2,3,...,NIP+1 (3E10.0)

Define the following if ICST = 0.

Columns	Quantity	Format
1-10	s coordinate of integration point	E10.0
11-20	t coordinate of integration point	E10.0
21-30	Weighting factor, A_{ri} typically the area associated with integration point divided by actual cross sectional area. $A_{ri} = Aj/A$	E10.0

Define the following card if ICST is nonzero.

Cards 2 (6E10.0)

Columns	Quantity	Format
1-10	w, flange width	E10.0
11-20	t_f, flange thickness	E10.0
21-30	d, depth	E10.0
31-40	t_w, web thickness	E10.0
41-50	s_{ref}, location of reference surface normal to s, for the Hughes-Liu beam only.	E10.0
51-60	t_{ref}, location of reference surface normal to t, for the Hughes-Liu beam only.	E10.0

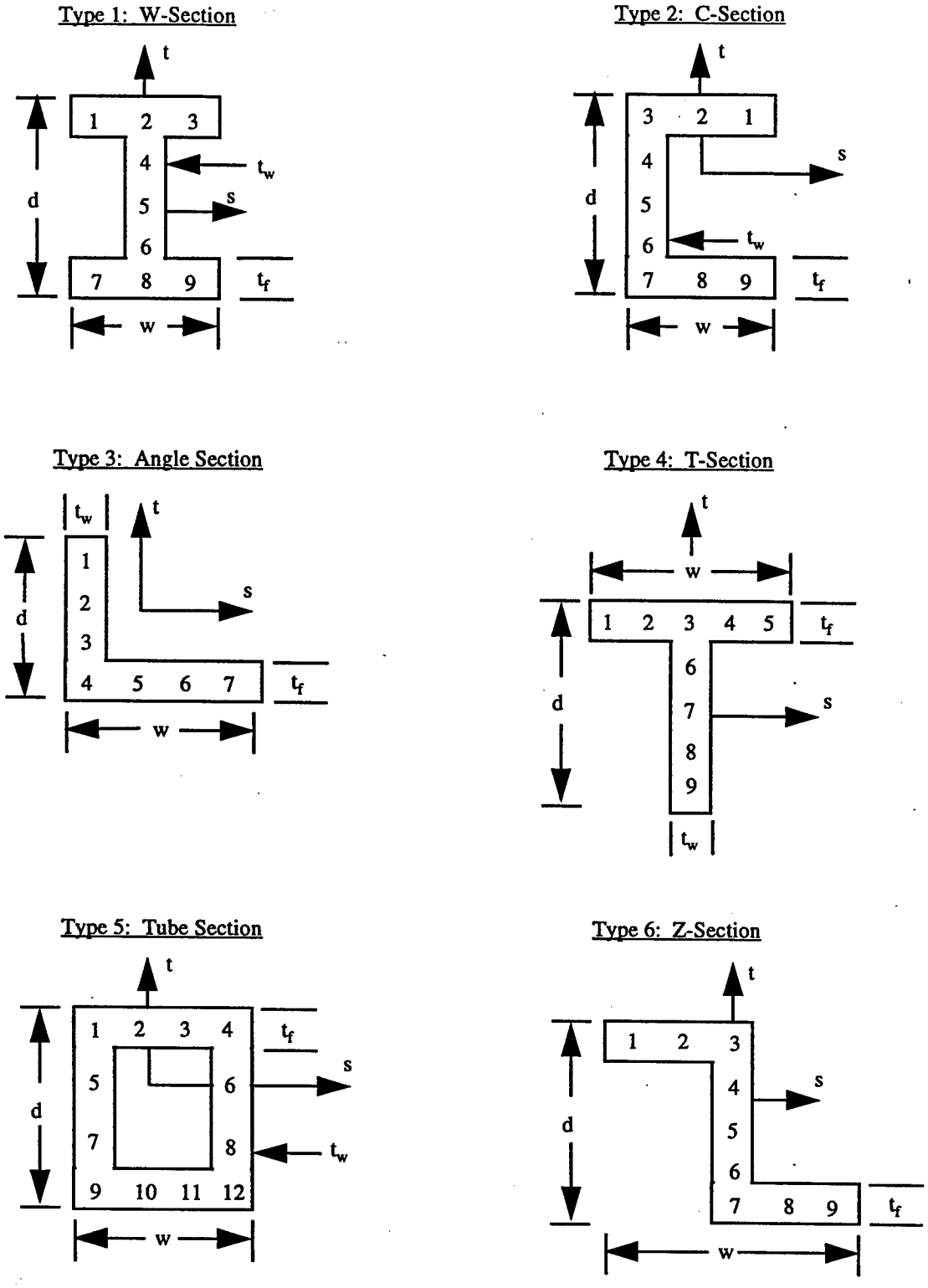
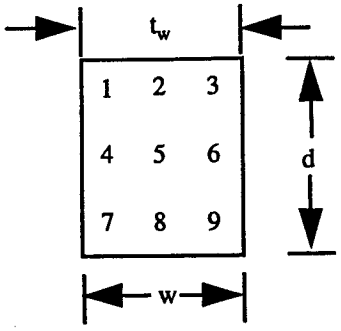
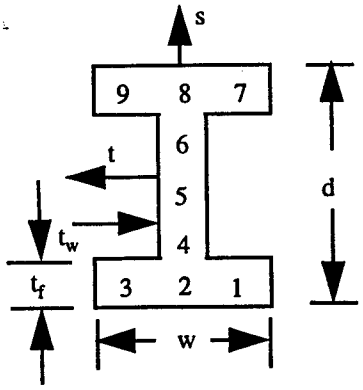


Figure 2-11. Standard cross-section library with integration point shown.

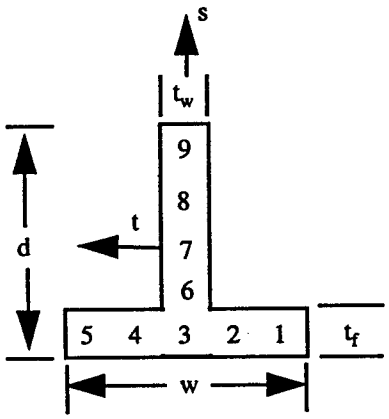
Type 7: Trap Section



Type 11: Rotated W



Type 14: Rotated T



Type 15: Rotated Tube

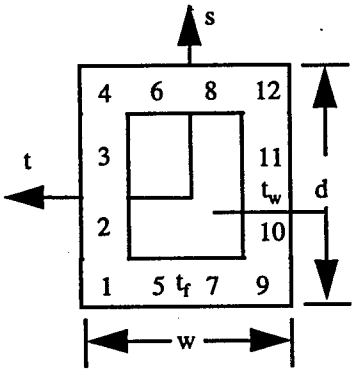


Figure 2-11. Standard cross-section library with integration point shown. (Continued)

2.5 USER DEFINED INTEGRATION RULES FOR SHELLS.

Define NUSSIR card sets in this section.

Card 1 (2I5)

Columns	Quantity	Format
1-15	Number of integration points, NIP	15
6-10	IESOP, equal spacing of integration points option EQ.0: integration points are defined below EQ.1: integration points are equally spaced through thickness such that the shell is subdivided into NIP layers of equal thickness	15

Card 2,3,...,NIP+1 (2E10.0,I5)

Define these cards if and only if IESOP equals 0.

Columns	Quantity	Format
1-10	Coordinate of integration point in range -1 to 1	E10.0
11-20	Weighing factor, typically the thickness associated with the integration point divided by actual shell thickness.	E10.0
21-25	Optional material number if different than the number specified on the element card. The material type is not allowed to change.	I5

2.6 NODAL POINT CARDS.

(2I5,3E20.0,2I5) or (I8,I5,3E20.0,I5) for LARGE option

Define NUMNP nodal point cards in this section.

Columns		Quantity	Format	
1-50	(1-80)	Define nodes, up to ten per card	10I5	(10I8)
1-15	(1-8)	Node number	I5	(I8)
6-10	(9-13)	Displacement boundary condition code EQ.0: no constraints EQ.1: constrained x displacement EQ.2: constrained y displacement EQ.3: constrained z displacement EQ.4: constrained x and y displacements EQ.5: constrained y and z displacements EQ.6: constrained z and x displacements EQ.7: constrained x, y, and z displacements EQ.8: constrained in direction specified on the first boundary condition card read in Section 13 below EQ.9: constrained in direction specified on the second boundary condition card read in Section 13 below	I5	(I5)
11-30	(14-33)	x-coordinate	E20.0	(E20.0)
31-50	(34-53)	y-coordinate	E20.0	(E20.0)
51-70	(54-73)	z-coordinate	E20.0	(E20.0)
71-75	(-)	Nodal increment k	I5	(omit)
76-80	(74-78)	Rotational boundary condition code EQ.0: no constraints EQ.1: constrained x rotation EQ.2: constrained y rotation EQ.3: constrained z rotation EQ.4: constrained x and y rotations EQ.5: constrained y and z rotations EQ.6: constrained z and x rotations EQ.7: constrained x, y, and z rotations	I5	(I5)

2.7 ELEMENT CARDS FOR SOLID ELEMENTS.

(11I5) or (I8, I5, 8I8) for LARGE option

Define NUMELH element cards in this section.

Columns		Quantity	Format	
1-5	(1-8)	Element number	I5	(I8)
6-10	(9-13)	Material number	I5	(I5)
11-15	(-)	Increment k	I5	(omit)
16-20	(14-21)	Nodal point n_1	I5	(I8)
21-25	(22-29)	Nodal point n_2	I5	(I8)
26-30	(30-37)	Nodal point n_3	I5	(I8)
.		. .		.
.		. .		.
.		. .		.
51-55	(70-77)	Nodal point n_8	I5	(I8)

Element cards are assumed to be in element number sequence. Omitted data are automatically generated with respect to the first card prior to the omitted data as follows:

$$n_j^{i+1} = n_j^i + k \tag{2.68}$$

The material properties for the generated elements and the mesh generation parameter k are taken from the first card. The default value of k is 1.

Nodal points n_1 - n_8 define the corner nodes of the 8-node solid elements. Elements having fewer than 8 nodes are obtained by repeating one or more nodes. Four, six, and eight node elements are shown in Figure 12. Input of nodes on the element cards for the former two elements would taken the form

4-node	n_1 n_2 n_3 n_4 n_4 n_4 n_4 n_4
6-node	n_1 n_2 n_3 n_4 n_5 n_5 n_6 n_6

Note: In all cases the first four node numbers must be unique.

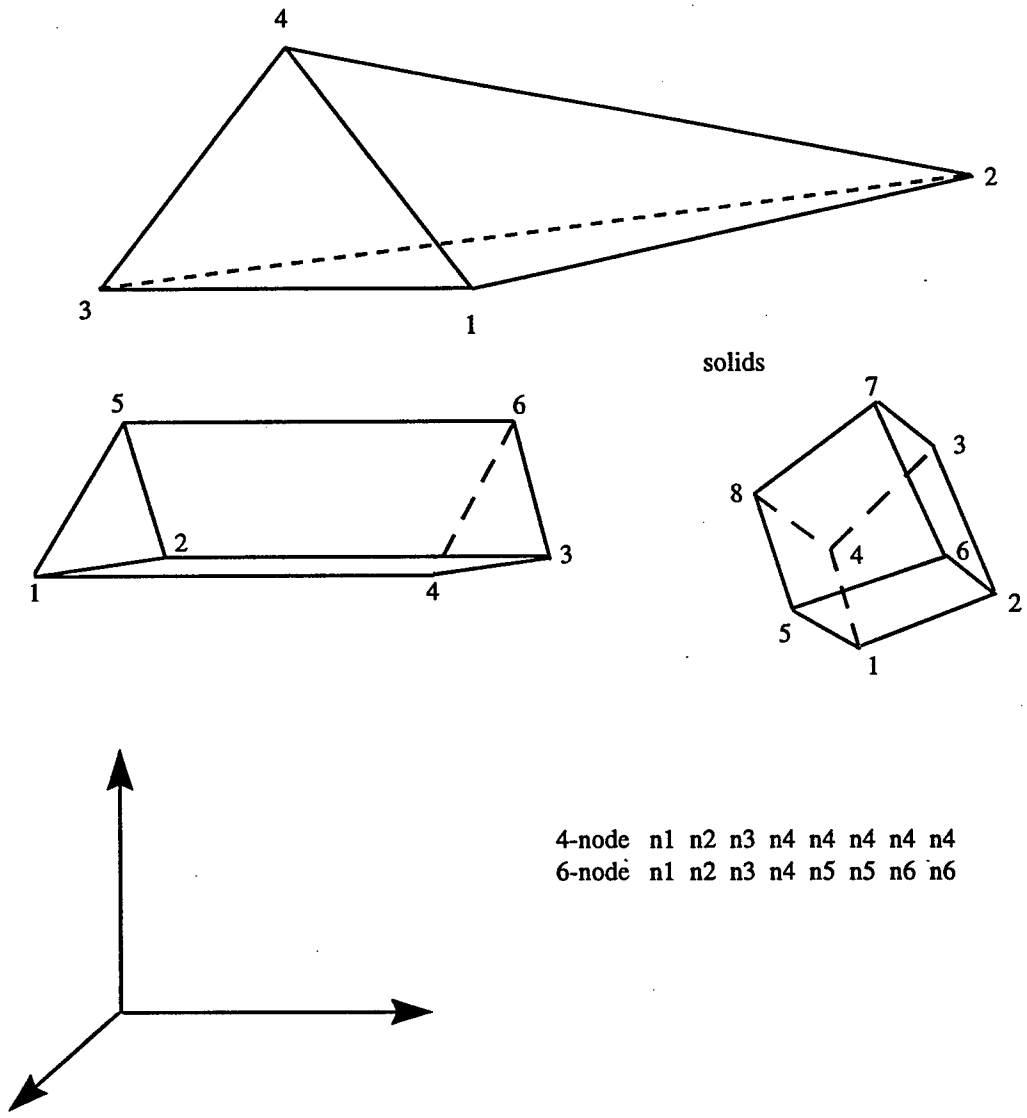


Figure 2-12. Four, six, and eight node solid elements.

2.8 ELEMENT CARDS FOR BEAM ELEMENTS.

(6I5,5E10.0) or (I8,I5,3I8) for LARGE option

Define NUMELB element cards in this section.

Columns		Quantity	Format	
1-5	(1-8)	Element number	15	(I8)
6-10	(9-13)	Material number	15	(I8)
11-15	(-)	Increment k	I5	(omit)
16-20	(14-21)	Nodal point n_1	I5	(I8)
21-25	(22-29)	Nodal point n_2	I5	(I8)
26-30	(30-37)	Nodal point n_3 (see Figure 10)	I5	(I8)
31-40	(38-45)	Beam thickness in s direction at node 1 (Hughes-Liu) Area (Belytschko-Schwer)	E10.0	(E8.0)
41-50	(46-53)	Beam thickness in s direction at node 2 (Hughes-Liu) I_{ss} (Belytschko-Schwer)	E10.0	(E8.0)
51-60	(54-61)	Beam thickness in t direction at node 1 (Hughes-Liu) I_{tt} (Belytschko-Schwer)	E10.0	(E8.0)
61-70	(62-69)	Beam thickness in t direction at node 2 (Hughes-Liu) I_{rr} (Belytschko-Schwer)	E10.0	(E8.0)
71-78	(70-77)	Shear area (Belytschko-Schwer)	E10.0	(E8.0)

Element cards are assumed to be in element number sequence. Omitted data are automatically generated with respect to the first card prior to the omitted data as follows:

$$n_j^{i+1} = n_j^i + k \qquad (j = 1, 2) \tag{2.69}$$

The material properties, cross-sectional properties, and orientation node, n_3 for the generated elements and the mesh generation parameter k are taken from the card preceding the generated data. The default value of k is 1. If the thickness or cross-sectional properties are undefined, they are taken from the material cards.

2.9 ELEMENT CARDS FOR SHELL ELEMENTS.

(7I5,4E10.0,E5.0) or (I8,I5 4I8/5E10.0) for LARGE option

Define NUMELS element cards in this section.

Columns		Quantity	Format	
1-5	(1-8)	Element number	15	(I8)
6-10	(9-13)	Material number	15	(I5)
11-15	(-)	Increment k	I5	(omit)
16-20	(14-21)	Nodal point n_1 (see Figure 11)	I5	(I8)
21-25	(22-29)	Nodal point n_2	I5	(I8)
26-30	(30-37)	Nodal point n_3	I5	(I8)
31-35	(38-45)	Nodal point n_4	I5	(I8)
****		**second card here if LARGE option is active**	****	
36-45	(1-10)	Shell thickness at node 1 (optional)	E10.0	(E10.0)
46-55	(11-20)	Shell thickness at node 2 (optional)	E10.0	(E10.0)
56-65	(21-30)	Shell thickness at node 3 (optional)	E10.0	(E10.0)
66-75	(31-40)	Shell thickness at node 4 (optional)	E10.0	(E10.0)
76-80	(41-50)	Orthotropic material angle (optional)	E5.00	(E10.0)

Element cards are assumed to be in element number sequence. Omitted data are automatically generated with respect to the first card prior to the omitted data as follows:

$$n_j^{i+1} = n_j^i + k \tag{2.70}$$

The material and cross-sectional properties for the generated elements and the mesh generation parameter k are taken from the card preceding the generated data. The default value of k is l. If the thicknesses are undefined, they are taken from the material cards. Triangular elements are defined by repeating the third node, i.e., by setting $n_4 = n_3$.

2.10 ELEMENT CARDS FOR 8-NODE SOLID SHELL.

(11I5) or (I8,I5,8I8) for LARGE option

Define NUMELT element cards in this section.

Columns		Quantity	Format	
1-5	(1-8)	Element number	15	(I8)
6-10	(9-13)	Material number	I5	(I5)
11-15	(-)	Increment k	I5	(omit)
15-20	(14-21)	Nodal point n_1	I5	(I8)
21-25	(22-29)	Nodal point n_2	I5	I8)
26-30	(30-37)	Nodal point n_3	I5	(I8)
51-55	(70-77)	Nodal point n_8	I5	(I8)
.		. .		.
.		. .		.
.		. .		.
.		. .		.

Element cards are assumed to be in element number sequence. Omitted data are automatically generated with respect to the first card prior to the omitted data as follows:

$$n_j^{i+1} = n_j^i + k \tag{2.71}$$

The material properties for the generated elements and the mesh generation parameter k are taken from the first card. The default value of k is 1.

Nodes n_1 to n_4 define the lower surface, and nodes n_5 to n_8 define the upper surface, Figure 13. The integration points lie along the t-axis where n_1- n_2 determine the r-axis and n_1- n_4 determine the s-axis. Extreme care must be used in defining the connectivity to insure proper orientation.

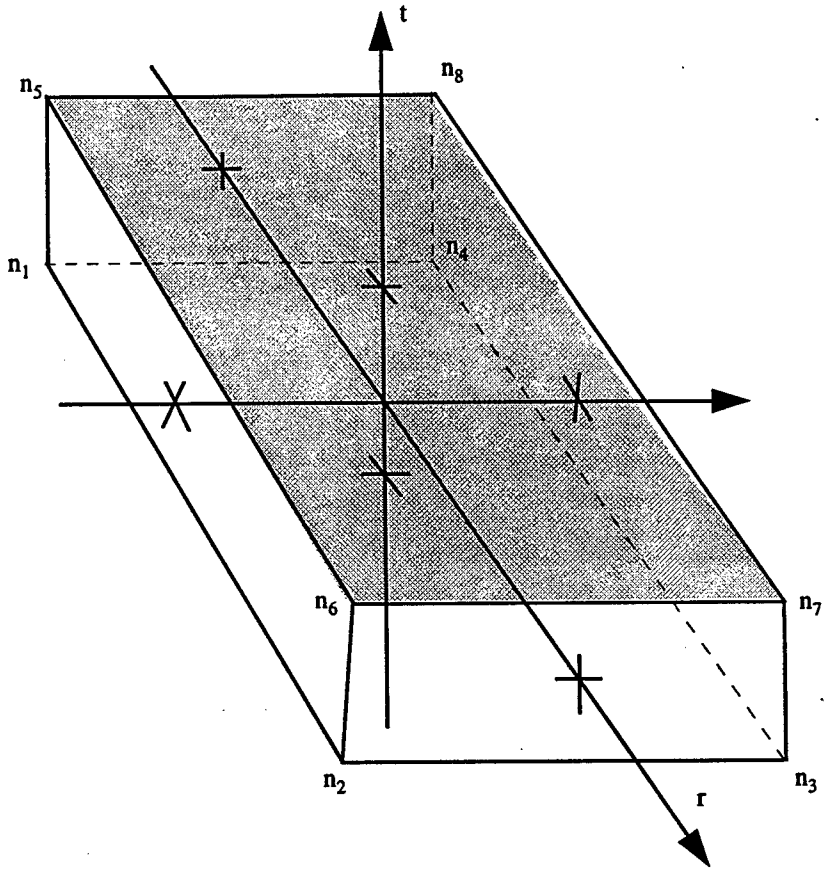


Figure 2-13. Solid 8-node shell element.

2.11 INTERFACE SEGMENT DEFINITION.

Define NUMIFS Interface Segments
(6I5) or (5I8) for LARGE option
(Interface Segment Cards)

Columns		Quantity	Format	
1-5	(1-8)	Interface segment number	I5	(I8)
6-10	(-)	Increment k	I5	(omit)
11-15	(9-16)	Nodal point n_1	I5	(I8)
16-20	(17-24)	Nodal point n_2	I5	(I8)
21-25	(25-32)	Nodal point n_3	I5	(I8)
26-30	(33-40)	Nodal point n_4	I5	(I8)

Omitted data are automatically generated with respect to the first card prior to the omitted data as

$$n_j^{i+1} = n_j^i + k \tag{2.72}$$

The generation parameter k is taken from the first card. Nodal numbering can be either clockwise or counterclockwise. Nodal points n_1 - n_4 define the corner nodes of the segments as shown in Figure 17. Triangular segments are defined by repeating a node.

Interface same segments are used to define a surface for which the displacements and velocities will be sound during an analysis. The surface is then used as the master surface of a tied interfaced in a second analysis, where the discretization may be arbitrarily modified.

2.12 VECDYNA3D/JOY INTERFACE DEFINITION.

(2I5) or (2I8) for LARGE options

Define the number of nodes specified on Card 3 in Section 2.

Columns		Quantity	Format	
1-5	(1-8)	Interface node number	I5	(I8)
6-10	(9-16)	Nodal point number	I5	(I8)

Omitted interface nodes are automatically generated by incrementing the nodal point numbers by

$$\frac{n_i - n_j}{in_i - in_j} \tag{2.73}$$

where in_i and in_j are interface node numbers on two successive cards and n_i and n_j are their corresponding node numbers.

2.13 NODAL SINGLE POINT CONSTRAINTS.

(2I5,4X,6I1,2I5) or (I8,I5,4X,6I1,2I8) for LARGE option

Define NODSPC cards.

Columns		Quantity	Format	
1-5	(1-8)	First nodal point number, IFIRST	I5	(I8)
6-10	(9-13)	Local coordinate system number < NSPCOR+1	I5	(I5)
11-14	(14-17)	Blank		
15	(18)	Insert 1 (0) for (no) translational constraint in local x-direction	I1	(I1)
16	(19)	Insert 1 (0) for (no) translational constraint in local y-direction	I1	(I1)
17	(20)	Insert 1 (0) for (no) translational constraint in local z-direction	I1	(I1)
18	(21)	Insert 1 (0) for (no) rotational constraint about local x-axis	I1	(I1)
19	(22)	Insert 1 (0) for (no) rotational constraint about local y-axis	I1	(I1)
20	(23)	Insert 1 (0) for (no) rotational constraint about local z-axis	I1	(I1)
21-25	(24-28)	Last nodal point number, ILAST EQ.0: ILAST = IFIRST	I5	(I8)
26-30	(29-39)	Increment for generation EQ.0: default set to 1	I5	(I8)

2.14 LOCAL COORDINATE SYSTEMS.

Define NSPCOR local coordinate systems for single point constraints. The xy plane is described by two vectors: the local x axis and another vector lying in the plane. The local z axis is the cross product of these two vectors. The local y axis is found by taking the cross product of the local z and x axes.

(I5,6E10.0)

Columns	Quantity	Format
1-5	Local coordinate system number < NSPCOR+1	I5
6-15	x-coordinate of local x-axis. Origin lies at (0,0,0)	E10.0
16-25	y-coordinate of local x-axis	E10.0
26-35	z-coordinate of local x-axis	E10.0
36-45	x-coordinate of local inplane vector	E10.0
46-55	y-coordinate of local inplane vector	E10.0
56-65	z-coordinate of local inplane vector	E10.0

2.15 SLIDING BOUNDARY PLANE CARDS (4E10.0).

Define the number of cards specified on Card 3 in Section 2.

Columns	Quantity	Format
1-10	x-coordinate of vector	E10.0
11-20	y-coordinate of vector	E10.0
21-30	z-coordinate of vector	E10.0
31-40	Constraint option EQ.0.0: node is constrained to move on normal plane EQ.1.0: node is constrained to translate in vector direction	E10.0

Any node may be constrained to move on an arbitrarily oriented plane or line. Each boundary condition card defines a vector originating at (0,0,0) and terminating at the coordinates defined above. Since an arbitrary magnitude is assumed for this vector, the specified coordinates are nonunique.

2.16 SYMMETRY PLANES WITH FAILURE.

Define the number of cards specified on the third control card.

Card 1 (I5,7E10.0)

Columns	Quantity	Format
1-5	Number of segments in symmetry plane, NSGNDS	I5
6-15	x-coordinate of tail of any outward drawn normal vector originating on the wall and terminating in the body (vector points fromsymmetry plane into body)	E10.0
16-25	y-coordinate of tail	E10.0
26-35	z-coordinate of tail	E10.0
36-45	x-coordinate of head	E10.0
46-55	y-coordinate of head	E10.0
56-65	z-coordinate of head	E10.0
66-75	Tensile failure stress (> 0) E10.0	

Card 2,3,...,NSGNDS+1 (5I5,E10.0) or (5I8,E10.0) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Segment number	I5	(I8)
6-10	(9-16)	Nodal point n_1	I5	(I8)
11-15	(17-24)	Nodal point n_2	I5	(I8)
16-20	(25-32)	Nodal point n_3	I5	(I8)
21-25	(33-40)	Nodal point n_4	I5	(I8)
26-35	(41-50)	Failure stress if different from default value	E10.0	(E10.0)

Triangular segments are defined by repeating the last node.

2.17 NODAL TIME HISTORY BLOCKS.

(16I5) or (10I8) for LARGE option

Skip this section if the number of nodal time history blocks is zero. Otherwise, define up to 2000 history blocks that may contain a total of 2000 nodes. Use only the number of cards required to define all blocks.

Columns		Quantity	Format	
1-5	(1-8)	First node of first time history block	I5	(I8)
6-10	(9-16)	Last node of first time history block	I5	(I8)
11-15	(17-24)	First node of second time history block	I5	(I8)
16-20	(25-32)	Last node of second time history block	I5	(I8)
.	.	.	.	
.	.	.	.	
.	.	.	.	
.	.	.	.	

2.18 ELEMENT TIME HISTORY BLOCKS.

(16I5) or (10I8) for LARGE option
(Solid Elements)

Skip this section if the number of solid element time history block is zero. Otherwise, define up to 2000 time history blocks that may contain a total of 2000 elements. Use only the number of cards required to define all blocks.

Columns		Quantity	Format	
1-5	(1-8)	First element of first time history block	I5	(I8)
6-10	(9-16)	Last element of first time history block	I5	(I8)
11-15	(17-24)	First element of second time history block	I5	(I8)
16-24	(25-32)	Last element of second time history block	I5	(I8)
.	.	.		
.	.	.		
.	.	.		

(Beam Elements)

Skip these cards if the number of beam element time history blocks is zero. Up to 2000 time history blocks may be defined containing a total of 2000 elements

(Shell Elements)

Skip these cards if the number of shell element time history blocks is zero. Up to 2000 time history blocks may be defined containing a total of 2000 elements

(Solid Shell Elements)

Skip these cards if the number of solid shell element time history blocks is zero. Up to 2000 time history blocks may be defined containing a total of 2000 elements.

2.19 DENSITY VS. DEPTH CURVE FOR GRAVITY LOADING.

Skip this section if the number of points in the density versus depth curve is zero; otherwise, supply NUMDP+1 cards.

Card 1 (E10.0,4x,I1,I3I5)

Columns	Quantity	Format
1-10	Gravitational acceleration E10.0	
15	Direction of loading EQ.1: global x EQ.2: global y EQ.3: global z	I1
16-20	Material of materials to be initialized (< 13) EQ.0: all EQ.n: define list of n materials below (n < 13)	I5
21-25	Material number of first material to be initialized	I5
26-30	Material number of second material to be initialized	I5
.	. .	.
.	. .	.
.	. .	.
.	. .	.

Cards 2,3,...,NUMDP+1 (2E10.0)

Columns	Quantity	Format
1-10	Mass density	E10.0
11-20	Depth	E10.0

2.20 BRODE FUNCTION DATA (BRODE).

Skip this section if columns 21-25 of Card 3, Section 2, is blank; otherwise, enter two cards for the pertinent Brode function data.

Card 1 (6E10.0,2I5)

Columns	Quantity	Format
1-10	Yield (Kt)	E10.0
11-20	Height of burst	E10.0
21-30	XBO	E10.0
31-40	YBO	E10.0
41-50	ZBO (DYNA coordinates of Brode origin (space, time))	E10.0
51-60	TBO	E10.0
61-65	*Load curve number giving time of arrival versus range relative to Brode origin (space, time)	E10.0
66-70	Load curve giving yield scaling versus scaled time (time relative to Brode origin divided by [yield$^{(**1/3)}$])	E10.0

Card 2 (3E10.0)

Columns	Quantity	Format
1-10	Conversion factor - kft to DYNA length units	E10.0
11-20	Conversion factor - milliseconds to DYNA time units	E10.0
21-30	Conversion factor - psi to DYNA pressure units	E10.0

*Both load curves must be specified for the variable yield option. If this option is used, the shock time of arrival is found from the time of arrival curve. The yield used in the Brode formulas is computed by taking the value from the yield scaling curve at the current time/[yield$^{(**1/3)}$] and multiplying that value by yield.

2.21 CROSS SECTION DEFINITION FOR FORCE OUTPUT.

For each cross section define the following control cards.

Card 1,2,...,NUMCSD (3I5)

Columns	Quantity	Format
1-5	Number of nodes	I5
6-10	Number of beam elements I5	
11-15	Number of shell elements	I5

Define NUMCSD sets of cards with the information requested below.

Card NUMCSD+1,...(8I10)

Columns	Quantity	Format
1-10	First cross section node	I10
11-20	Second cross section node	I10
.	.	.
.	.	.
.	.	.
71-80	Eighth cross section node	I10

Use as many cards as needed to define the beam elements.

Columns	Quantity	Format
1-10	First beam element	I10
11-20	Second beam element	I10
.	.	.
.	.	.
.	.	.
71-80	Eighth beam element	I10

Use as many cards as needed to define the shell elements in the cross-section.

Columns	Quantity	Format
1-10	First shell element	I10
11-20	Second shell element	I10
.	.	.
.	.	.
.	.	.
71-80	Eighth shell element	I10

2.22 LOAD CURVE CARDS.

Define the number of load curve sets specified on Card 4. Repeat the following cards for each set:

Card 1 (3I5)

Columns	Quantity	Format
1-5	Load curve number	I5
6-10	Number of points in load curve, NPTS	I5
11-15	Stress initialization by dynamic relaxation EQ.0: load curve used in transient analysis only EQ.1: load curve used in stress initialization but not analysis EQ.2: load curve applies to both initialization and analysis	I5

Card 2,...,NPTS+1 (2E10.0)

Columns	Quantity	Format
1-10	Time	E10.0
11-20	Load or function value	E10.0

2.23 CONCENTRATED NODAL LOADS AND FOLLOWER FORCES.

(3I5, E10.0,3I5) or (I8,2I5,E10.0,3I8) for LARGE option

Define the number of concentrated nodal point loads specified on Card 4.

Columns		Quantity	Format
1-5	(1-8)	Nodal point number, m, on which this load acts	I5 (I8)
6-10	(9-13)	Direction in which this load acts, IDR EQ.1: x-direction EQ.2: y-direction EQ.3: z-direction EQ.4: follower force EQ.5: moment about the global x-axis EQ.6: moment about the global y-axis EQ.7: moment about the global z-axis	I5 (I5)
11-15	(14-18)	Load curve number	I5 (I5)
16-25	(19-28)	Scale Factor (default =1.0)	E10.0 (E10.0)
26-30	(29-36)	Nodal point m_1 (see comment below)	I5 (I8)
31-35	(37-44)	Nodal point m_2	I5 (I8)
36-40	(45-52)	Nodal point m_3	I5 (I8)
41-45	(53-60)	Local coordinate system number defined in Section 14 EQ.0: global is assumed	I5 (I8)
46-50	(61-68)	Mass scaling option EQ.1: scale by nodal mass	I5 (I8)

Nodes m_1, m_2, m_3, must be defined if IDR=4. The follower force acts normal to the plane defined by these nodes as depicted in Figure 14.

In underwater shock analysis, axial beam hydrostatics are applied with nodal forces which are active only for stress initialization.

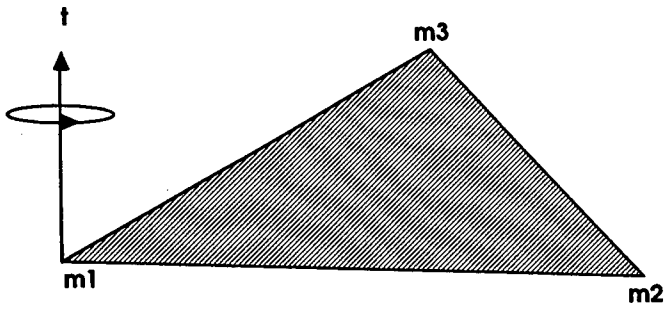


Figure 2-14. Follower force acting on plane defined by nodes m_1, m_2, and m_3. In this case, the load is applied to node m_1. Positive force acts in the positive t-direction.

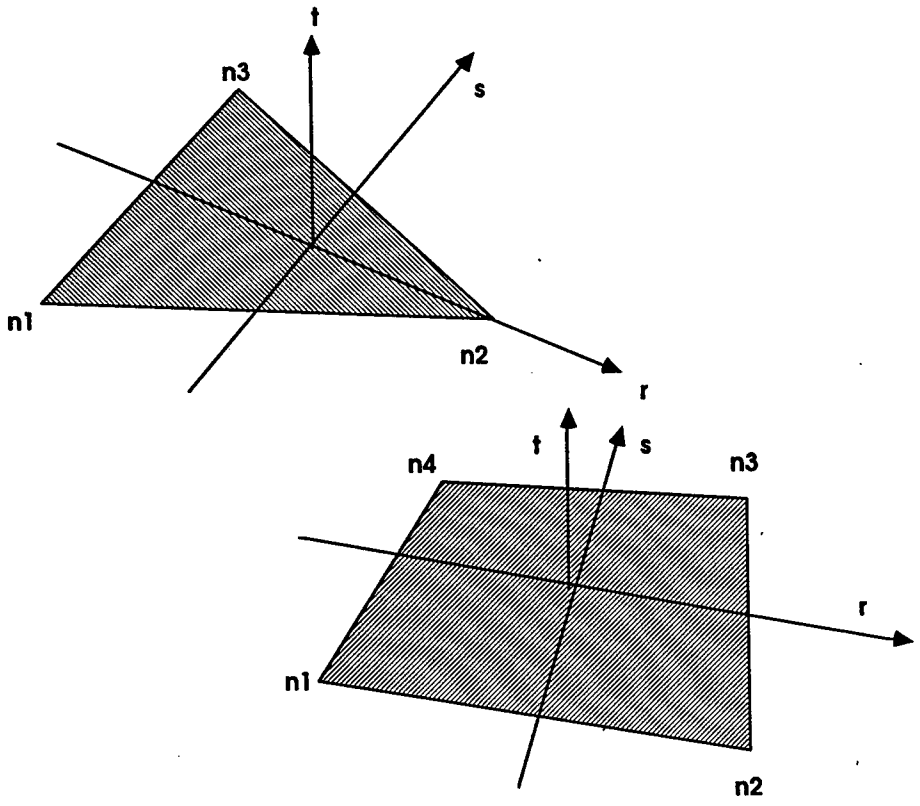


Figure 2-15. Nodal numbering for pressure cards. Positive pressure acts in the negative t-direction.

2.24 PRESSURE BOUNDARY CONDITION CARDS.

(6I5,5E10.0) or (I5,4I8,4E10.0) for LARGE option

Define the number of cards specified on Card 4 in Section 2.

Columns		Quantity	Format	
1-5	(-)	Pressure card number	I5	(omit)
6-10	(1-5)	Load curve number LT.O: Brode function is used to determine pressure	I5	(I5)
11-15	(6-13)	Nodal point n_1 (see Figure 15)	I5	(I8)
16-20	(14-21)	Nodal point n_2	I5	(I8)
21-25	(22-29)	Nodal point n_3	I5	(I8)
26-30	(30-37)	Nodal point n_4	I5	(I8)
31-40	(38-47)	Multiplier of load curve at node n_1 EQ.0.0: default set to 1.0	E10.0	(E10.0)
41-50	(48-57)	Multiplier of load curve at node n_2 EQ.0.0: default set to 1.0	E10.0	(E10.0)
51-60	(58-67)	Multiplier of load curve at node n_3 EQ.0.0: default set to 1.0	E10.0	(E10.0)
61-70	(68-77)	Multiplier of load curve at node n_4 EQ.0.0: default set to 1.0	E10.0	(E10.0)
71-80	(-)	Time pressure begins acting on surface	E10.0	(omit)

The load curve multipliers may be used to increase or decrease the pressure. The time value is not scaled. Triangular segments are defined by repeating node n_3.

In underwater shock analysis with hydrostatics, the hydrostatic pressure is typically applied with these cards and a load curve which is active for stress initialization but not analysis.

2.25 VELOCITY/ACCELERATION SPECIFICATION CARDS FOR NODES AND RIGID BODIES.

(3I5,4E10.0,I5) or (I8,2I5,4E10.0,I5) for LARGE option

Define the number of cards specified on Card 4.

Columns		Quantity	Format	
1-5	(1-8)	Nodal point number or rigid body to which this card applies GT.0: nodal pointrigid body LT.0: absolute value is material number of the rigid body	I5	(I8)
6-10	(9-13)	Load curve number	I5	(I5)
11-15	(14-18)	Applicable degrees-of-freedom EQ.1: x-translational degree-of-freedom EQ.2: y-translational degree-of-freedom EQ.3: z-translational degree-of-freedom EQ.4: translational velocity in direction of vector defined below EQ.5: x-rotational degree-of-freedom EQ.6: y-rotational degree-of-freedom EQ.7: z-rotational degree-of-freedom EQ.8: rotational velocity about vector defined below EQ.9: y and z degrees-of-freedom for node rotating about the global x-axis EQ.10: z and x degrees-of-freedom for node rotating about the global y-axis EQ.11: x and y degrees-of-freedom for node rotating about the global z-axis	I5	(I5)
16-25	(19-28)	Scale vector	E10.0	(E10.0)
26-35	(29-38)	x-coordinate of vector	E10.0	(E10.0)
36-45	(39-48)	y-coordinate of vector	E10.0	(E10.0)
46-55	(49-58)	z-coordinate of vector	E10.0	(E10.0)
56-60	(59-63)	velocity/acceleration flag EQ.0: velocity (rigid bodies and nodes) EQ.1: acceleration (nodes only)	I5	(I5)

The acceleration flag pertains to nodes only. Nodal velocity/acceleration specification for nodes that belong to rigid bodies is not allowed.

2.26 STONEWALL CARDS.

Define the number of stonewalls specified on Card 4. Repeat the following set of cards for each stonewall.

Card 1

(I5,6E10.0,3I5) or (I8,6E10.0,2I5,I2) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Number of slave nodes	I5	(I8)
6-15	(9-18)	x-coordinate of tail of any outward drawn normal vector originating on wall (tail) and terminating in space (head)	E10.0	(E10.0)
16-25	(19-28)	y-coordinate of tail	E10.0	(E10.0)
26-35	(29-38)	z-coordinate of tail	E10.0	(E10.0)
36-45	(39-48)	x-coordinate of head of normal vector z′	E10.0	(E10.0)
46-55	(49-58)	y-coordinate of head of normal vector z′	E10.0	(E10.0)
56-65	(59-68)	z-coordinate of head of normal vector z′	E10.0	(E10.0)
66-70	(69-73)	Flag for moving stonewall, IMSWF EQ.0: stonewall is fixed in space EQ.1: stonewall has an initial mass and velocity	I5	(I5)
71-75	(74-78)	Stick condition EQ.0: frictionless sliding after contact EQ.1: no sliding after contact	I5	(I5)
76-80	(79-80)	Option for limiting the size of the stonewall, LIMIT EQ.0: stonewall extends to infinity EQ.1: size and orientation is defined	I5	(I2)

The tail of the vector defined above is at the origin of the stonewall if LIMIT=1.

Card 1+LIMIT

(5E10.0)

Define this card if and only if LIMIT=1.

Columns	Quantity	Format
1-10	x-coordinate of head of edge vector x′	E10.0
11-20	y-coordinate of head of edge vector x′	E10.0
21-30	z-coordinate of head of edge vector x′	E10.0
31-40	Length of x′ edge EQ.0.0: extends from negative to positive infinity	E10.0
41-50	Length of y′ edge EQ.0.0: extends from negative to positive infinity	E10.0
	(x′ and y′ should not both be zero for LIMIT=1).	

Define the following card if and only if IMSWF=1.

Card 1+ILIMIT+IMSWF

(2E10.0)

Columns	Quantity	Format
1-10	Total mass of stonewall	E10.0
11-20	Initial velocity of stonewall in direction of defining vector	E10.0

Card 1+LIMIT+IMSWF,...,

(2I5) or (2I8) for LARGE option

Define the following card if and only if LIMIT =1.

Columns		Quantity	Format	
1-10	(1-8)	Slave number	I5	(I8)
6-10	(9-16)	Nodal point number	I5	(I8)

A stonewall is a planar surface which extends to infinity in every direction and is defined by a normal vector of arbitrary magnitude drawn outward from the wall. Nodes that are designated as slave nodes cannot penetrate a stonewall; other nodes can penetrate.

Omitted slave nodes are automatically generated by incrementing the nodal point numbers by

$$\frac{n_i - n_j}{sn_i - sn_j} \tag{2.74}$$

where sn_i and sn_j are slave numbers on two successive cards and n_i and n_j are their corresponding node numbers.

2.27NODAL CONSTRAINT CARDS.

Define the number of nodal constraint sets specified on Card 4.

Card 1

(2I5) or (I8,I5) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Number of nodes that share at least one degree-of-freedom	I5	(I8)
6-10	(9-13)	Degrees-of-freedom in common EQ.1: x-translational degree-of-freedom EQ.2: y-translational degree-of-freedom EQ.3: z-translational degree-of-freedom EQ.4: x and y-translational degrees-of-freedom EQ.5: y and z-translational degrees-of-freedom EQ.6: z and x-translational degrees-of-freedom EQ.7: x, y, and z-translational degrees-of-freedom	I5	(I5)

(Card 2)

(16I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Nodal point number of first node to be tied	I5	(I8)
6-10	(9-16)	Nodal point number of second node to be tied	I5	(I8)
11-15	(17-24)	Nodal point number of third node to be tied	I5	(I8)
.		.		.
.		.		.
.		.		.

2.28 INITIAL CONDITIONS.

(I5,3E10.0,I5) or (I8,3E10.0,I5) for LARGE option

Skip this section if the initial condition parameter on Card 4 is zero.

Columns		Quantity	Format	
1-5	(1-8)	Nodal point number	I5	(I8)
6-15	(9-18)	Initial velocity in x-direction	E10.0	(E10.0)
16-25	(19-28)	Initial velocity in y-direction	E10.0	(E10.0)
26-35	(29-38)	Initial velocity in z-direction	E10.0	(E10.0)
36-40	(39-43)	Node increment	I5	(I5)

2.29 SLIDING INTERFACE DEFINITIONS (Hallquist, Benson and Hallquist)

Define the number of sliding interfaces specified on Card 4. Define NUMSI control cards.

Cards 1,2,...,NUMSI

(3I5,3E10.0,3I5,2E10.0) or (2I8,I5,3E10.0,3I5,2E7.0) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Number of slave segments (1-4, 9 & 10) or nodes (5-8)	I5	(I8)
6-10	(9-16)	Number of master segments (NMS)	I5	(I8)
11-15	(17-21)	Type number: 1 - sliding 2 - tied 3 - sliding, impact, friction 4 - single surface contact (NMS = 0) 5 - discrete nodes impacting surface 6 - discrete nodes tied to surface 7 - shell edge tied to shell surface 8 - nodes spot welded to surface 9 - tiebreak interface 10 - one way treatment of sliding, impact, friction	I5	(I5)
16-25	(22-31)	Static coefficient of friction	E10.0	(E10.0)
26-35	(32-41)	Dynamic coefficient of friction	E10.0	(E10.0)
36-45	(42-51)	Exponential decay coefficient, d_v	E10.0	(E10.0)
46-50	(52-56)	Small penetration flag in contact search EQ.0 default EQ.1 penetration > element thickness ignored	I5	(I5)
51-55	(57-61)	Include slave side in printed force interface file	I5	(I5)
56-60	(62-66)	Include master side in printed force interface file	I5	(I5)
61-70	(67-73)	Scale factor on default slave penalty stiffness	E10.0	(E7.0)
71-80	(74-80)	Scale factor on default master penalty stiffness	E10.0	(E7.0)

Optional Cards for Eroding/Automatic Contact

Eroding/automatic contact control cards are input immediately after the control card for which they apply. If the number of slave nodes or segments is input as zero, one eroding/automatic contact section must be defined. If the number of master segments is input as zero and the single surface contact (type 4) was not specified than a second set of eroding/automatic contact cards will be read. An example on the usage of eroding contact is provided in this users manual..

Optional card 1 (5I5)

Columns	Quantity	Format
1-5	Number of materials for exterior boundary determination EQ.0: all materials will be included EQ.n: n material numbers will be input	I5
6-10	Symmetry plane option EQ.0: Turn this option off EQ.1: Do not include faces with normal boundary constraints	I5
11-15	Erosion/Interior node option EQ.0: only exterior boundary information is saved EQ.1: Storage is allocated so that eroding contact can occur. For type 5 contact, this option will make all of the bodies nodes into slaves.	I5
16-20	Shell contact segment orientation option EQ.0: Shell contact occurs in the direction of the shell normals EQ.1: Shell contact occurs in the opposite direction of the shell normals.	I5
21-25	Adjacent material treatment EQ.0: solid element faces are included only for free boundaries EQ.1: Solid element faces are included if they are on the boundary of the material subset.	I5

Only faces included within the box are considered for automatic contact. If the volume of the box is less than or equal to zero, then this option is turned off.

Optional card 2 (6E10.0)

Columns	Quantity	Format
1-10	Minimum x-coordinate	E10.0
11-20	Minimum y-coordinate	E10.0
21-30	Minimum z-coordinate	E10.0
31-40	Maximum x-coordinate	E10.0
41-50	Maximum y-coordinate	E10.0
51-60	Maximum z-coordinate	E10.0

Optional card 3

Columns	Quantity	Format
1-5	First material number	I5
6-10	Second material number	I5
11-15	Third material number	I5
.	.	.
.	.	.
.	.	.

Cards NUMSI+1,...,NUMSI+NSS

(6I5,2E10.0) or (5I8,2E10.0) for LARGE option

Define the following slave segment cards for sliding interfaces types 1-4, 9 and 10. If the slide surface type is 5-8 then skip the segment definitions and go to the node number definitions below.

Columns		Quantity	Format	
1-5	(1-8)	Slave segment number	I5	(I8)
6-10	(-)	Increment, k for generating missing segments	I5	(I8)
11-15	(9-16)	Nodal point n_1	I5	(I8)
16-20	(17-24)	Nodal point n_2	I5	(I8)
21-25	(25-32)	Nodal point n_3	I5	(I8)
26-30	(33-40)	Nodal point n_4	I5	(I8)
31-40	(41-50)	Normal failure stress (Type 9 only)	E10.0	(E10.0)
41-50	(51-60)	Shear failure stress (Type 9 only)	E10.0	(E10.0)

Define the discrete slave nodes for sliding interfaces type 5-8.

Columns		Quantity	Format	
1-5	(1-8)	Slave number EQ.0: increment slave number by 1	I5	(I8)
6-10	(9-16)	Nodal point number	I5	(I8)
11-20	(17-26)	S_n, normal force at failure	E10.0	(E10.0)
21-30	(27-36)	S_s, shear force at failure	E10.0	(E10.0)
31-40	(37-46)	n, exponent for normal force	E10.0	(E10.0)
41-50	(47-56)	m, exponent for shear force	E10.0	(E10.0)

Omitted data are automatically generated by incrementing the nodal point numbers by:

$$\frac{(n_i - n_j)}{(sn_i - sn_j)} \tag{2.75}$$

where sn_i, sn_j are the slave numbers on two successive cards and n_i and n_j are their corresponding node numbers.

Failure of the spot welds occurs when:

$$\left(\frac{f_n}{S_n}\right)^n + \left(\frac{f_s}{S_s}\right)^m \geq 1 \tag{2.76}$$

where f_n and f_s are the normal and shear interface force. Component f_n is nonzero for tensile values only. For tiebreaking interfaces (type 9) the above failure criterion is used with m=n=2.

The friction model is similar to the model for an elastic-perfectly plastic material. Corresponding to Young's modulus and the strain rate are the surface stiffness and the relative velocity between a node and the surface segment it contacts. The product of the velocity dependent coefficient of friction and the normal force is equivalent to the yield stress. An exponential function is used to smooth the transition between the static and kinetic coefficients of friction.

$$\mu = \mu_k + (\mu_s - \mu_k)e^{-d_v V_{\text{relative}}} \tag{2.77}$$

Buckling analysis requires the single surface contact algorithm to model a surface collapsing onto itself. Simply making the slave segments the same as the master segments will not work. The single surface algorithm is significantly more expensive to use than master-slave contact algorithms. Its use should be restricted to those situations where it is absolutely required.

Cards NUMSI+NSS+1,...,NUMSI+NSS+NMS

(6I5) or (5I8) for LARGE option

(master segment cards)

(for interface types 1-3 and 5-9)

Columns		Quantity	Format	
1-5	(1-8)	Master segment number	I5	(I8)
6-10	(-)	Increment k	I5	(omit)
11-15	(9-16)	Nodal point n_1	I5	(I8)
16-20	(17-24)	Nodal point n_2	I5	(I8)
21-25	(25-32)	Nodal point n_3	I5	(I8)
26-30	(33-40)	Nodal point n_4	I5	(I8)

Slave and master segment cards are assumed to be in sequence though the particular number assigned to a master segment is arbitrary. Omitted data are automatically generated with respect to the first card prior to the omitted data as

$$n_j^{i+1} = n_j^i + k \tag{2.78}$$

The generation parameter k is taken from the first card. Nodal numbering can be either clockwise or counterclockwise. Nodal points n_1 - n_4 define the corner nodes of the segments as shown in Figure 16. Triangular segments are defined by repeating a node.

Every slave and master segment in the contacting surfaces must be defined. No ordering is assumed or expected.

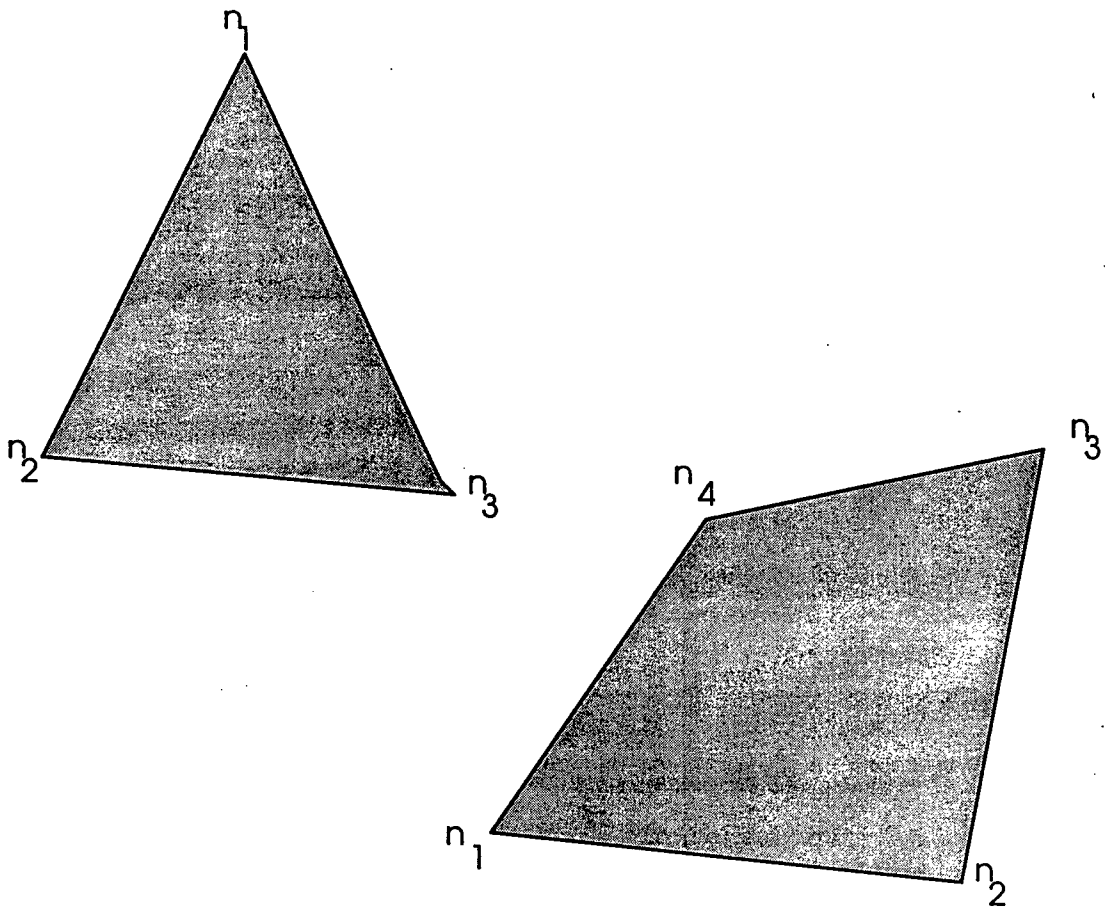


Figure 2-16. Numbering of slave and master segments.

2.30 TIE-BREAKING SHELL DEFINITIONS.

For each tiebreak shell slideline define the following control card.

Cards 1,2,...,NTBSL

(2I5) or (2I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Number of slave nodes, NSN	I5	(I8)
6-10	(9-16)	Number of master nodes, NMN	I5	(I8)

Define the following card sets for each tie-breaking shell slideline.

Card 1 (E10.0)

Columns	Quantity	Format
1-10	Default plastic failure strain	E10.0

Cards 2,3,4,...,NSN+1

(2I5,E10.0) OR (2I8,E10.0) for LARGE option

(Slave Nodes)

Columns		Quantity	Format	
1-5	(1-8)	Slave number EQ.0: the preceding slave number is incremented by 1	I5	(I8)
6-10	(9-16)	Nodal point number	I5	(I8)
11-20	(17-26)	Plastic strain at failure	E10.0	(E10.0)

Omitted data are automatically generated by incrementing the nodal point numbers by

$$\frac{\left(n_i - n_j\right)}{\left(sn_i - sn_j\right)} \tag{2.79}$$

where sn_i, sn_j are the slave numbers on two successive cards and n_i and n_j are their corresponding node numbers.

Cards NSN+2, NSN+3,...,NSN+NMN+1

(2I5,E10.0) or (2I8,E10.0) for LARGE option

(Master nodes)

Columns		Quantity	Format	
1-5	(1-8)	Master number EQ.0: the preceding slave number is incremented by 1	I5	(I8)
6-10	(9-16)	Nodal point number	I5	(I8)

Omitted data is generated as described above. The master nodes must be given in the order in which they appear as one moves along the surface. The slave surface must be to the left. Slidelines may not cross.

2.31 TIED NODE SETS WITH FAILURE.

Cards 1,2,3,...,NTNWF (2I5)

Columns	Quantity	Format
1-5	Number of tied node constraints, NTNC	I5
6-10	Number of nodes tied at each constraint (maximum)	I5

For each group of tied nodes (after definition of groups):

Cards NTNWF+1 (E10.0)

Columns	Quantity	Format
1-10	Default plastic strain for failure	E10.0

Card NTNWF+2,....,NTNWF+NTNC

(E10.0,12I5/(14I5)) or (E10.0,6x 6I8/ (10I8)) for LARGE option

Columns		Quantity	Format
1-10	(1-10)	Plastic strain required for failure	E10.0 (E10.0)
11-70	(-)	List up to 12 nodes tied together	12I5
***		**for LARGE option**	***
	(17-64)	List up to 6 nodes tied together	(6I8)

Use additional cards as necessary continuing with a format of 14I5 (or 10I8 for the LARGE option) on subsequent cards. This feature applies only to thin shell elements. The specified nodes are tied together until the average volume weighted plastic strain exceeds the specified value. Entire regions of individual shell elements may be tied together unlike the tie-breaking shell slidelines. The tied nodes are coincident until failure.

2.32 RIGID BODY MERGE CARDS (2I5).

Define NRBC rigid body merge cards in this section.

Columns	Quantity	Format
1-5	Master rigid body material number	I5
6-10	Slave rigid body material number	I5

The slave rigid body is merged with the master rigid body.

2.33 NODAL RIGID BODY CONSTRAINT SETS.

Input NUMRBS rigid body nodal constraint sets.

Card 1 (215)

Columns	Quantity	Format
1-15	Number of nodes in the rigid body	I15
16-20	Optional local coordinate system ID for output	I5

Card 2, 3, ..., (10I5), or (10I8) for LARGE option

Columns		Quantity	Format
1-50	(1-80)	Define nodes, up to ten per card	10I5 (10I8)

The equations of rigid body dynamics are used to update the motion of the nodes and therefore rotation of the nodal sets is admissable. Mass properties are determined from the nodal masses and coordinates.

2.34 EXTRA NODES FOR RIGID BODIES.

Define the number of card sets specified on control Card 6.

Card 1 (2I5)

Columns	Quantity	Format
1-5	Rigid body material number	I5
6-10	Number of extra nodes, NEN	I5

Cards 2,3,4,...,NEN+1

(10I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-50	(1-80)	Extra nodes, up to ten per card	10I5	(10I8)

2.35 JOINT CARDS.

Define the number of joint definitions specified on Card 6.

(E10.0,7I5) for (E10.0,I5,6I8) for LARGE option

Columns		Quantity	Format	
1-10	(1-10)	Relative penalty stiffness (default is 1.0)	E10.0	(E10.0)
11-15	(11-15)	Joint type EQ.1: Spherical EQ.2: Revolute EQ.3: Cylindrical EQ.4: Planar EQ.5: Universal EQ.6: Translational	I5	(I5)
16-20	(16-23)	Node 1	I5	(I8)
21-25	(24-31)	Node 2	I5	(I8)
26-30	(32-39)	Node 3	I5	(I8)
31-35	(40-47)	Node 4	I5	(I8)
36-40	(48-55)	Node 5	I5	(I8)
41-45	(56-63)	Node 6	I5	(I8)

At each timestep, the relative penalty stiffness is multiplied by a function dependent on the stepsize to give the maximum stiffness that will not destroy the stability of the solution. If the errors in the joint constraints are too large, the timestep must be reduced increasing the relative stiffness will have no affect.

2.36 BASE ACCELERATION IN X-DIRECTION (I5,E10.0,I5).

Skip this card if columns 41-45 of Card 4 are blank.

Columns	Quantity	Format
1-5	Load curve number	I5
6-15	Scale factor on x-acceleration EQ.0.0: default set to "1.0"	E10.0
16-20	Load curve number for dynamic relaxation phase (optional)	I5

2.37 BASE ACCELERATION IN Y-DIRECTION (I5,E10.0,I5).

Skip this card if columns 46-50 of Card 4 are blank.

Columns	Quantity	Format
1-5	Load curve number	I5
6-15	Scale factor on y-acceleration EQ.0.0: default set to "1.0"	E10.0
16-20	Load curve number for dynamic relaxation phase (optional)	I5

2.38 BASE ACCELERATION IN Z-DIRECTION (I5,E10.0,I5).

Skip this card if columns 51-55 of Card 4 are blank.

Columns	Quantity	Format
1-5	Load curve number	I5
6-15	Scale factor on z-acceleration EQ.0.0: default set to "1.0"	E10.0
16-20	Load curve number for dynamic relaxation phase (optional)	I5

2.39 ANGULAR VELOCITY ABOUT X-AXIS (I5,E10.0,I5).

Skip this card if columns 56-60 of Card 4 are blank.

Columns	Quantity	Format
1-5	Load curve number	I5
6-15	Scale factor on angular velocity EQ.0.0: default set to "1.0"	E10.0
16-20	Load curve number for dynamic relaxation phase (optional)	I5
21-30	x-center of rotation	E10.0
31-40	y-center of rotation	E10.0
41-50	z-center of rotation	E10.0

2.40 ANGULAR VELOCITY ABOUT Y-AXIS (I5,E10.0,I5).

Skip this card if columns 61-65 of Card 4 are blank.

Columns	Quantity	Format
1-5	Load curve number	I5
6-15	Scale factor on angular velocity EQ.0.0: default set to "1.0"	E10.0
16-20	Load curve number for dynamic relaxation phase (optional)	I5
21-30	x-center of rotation	E10.0
31-40	y-center of rotation	E10.0
41-50	z-center of rotation	E10.0

2.41 ANGULAR VELOCITY ABOUT Z-AXIS (I5,E10.0,I5).

Skip this card if columns 66-70 of Card 4 are blank.

Columns	Quantity	Format
1-5	Load curve number	I5
6-15	Scale factor on angular velocity (default = 1.0)	E10.0
16-20	Load curve number for dynamic relaxation phase (optional)	I5
21-30	x-center of rotation	E10.0
31-40	y-center of rotation	E10.0
41-50	z-center of rotation	E10.0

Nodal loads due to the angular velocity are always calculated with respect to the deformed configuration. Angular velocity is assumed to have the units of radians per unit time.

2.42 GENERALIZED BODY FORCE LOAD INPUT.

NUMGBL Card Sets (2 Cards)

Input NUMGBL cards for each generalized body load (see control card 8).

Card 1 (415,6E10.0) or (4I10,4E10.0) for LARGE option

Columns		Quantity	Format	
1-5	(1-10)	Beginning node for body load	(I5)	(I10)
6-10	(11-20)	Ending node for body load	(I5)	(I10)
11-15	(21-30)	Load curve number	(I5)	(I10)
16-20	(31-40)	Load curve number for dynamic relaxation phase (optional)	(I5)	(I10)
21-30	(41-50)	x-center of rotation	E10.0	(E10.0)
31-40	(51-60)	y-center of rotation	E10.0	(E10.0)
41-50	(61-70)	z-center of rotation	E10.0	(E10.0)
51-60	(71-80)	x-translational acceleration	E10.0	(E10.0)
61-70		y-translational acceleration	E10.0	
71-80		z-translational acceleration	E10.0	

Card 2 (20X,3E10.0) or (5E10.0) for LARGE option

Columns		Quantity	Format
blank	(71-80)	y-translational acceleration	(E10.0)
blank	(71-80)	z-translational acceleration	(E10.0)
21-30		x-angular velocity	E10.0
31-40		y-angular velocity	E10.0
41-50		z-angular velocity	E10.0

2.43 MOMENTUM DEPOSITION DATA.

(I5,4E10.0) or (I8,4E10.0) for LARGE option

Skip this section if columns 71-75 of Card 4, are blank. Otherwise enter one card as follows for each element receiving momentum deposition. This option applies only to solid elements.

Columns		Quantity	Format	
1-5	(1-8)	Element number	(I5)	(I8)
6-15	(9-18)	x-momentum	E10.0	(E10.0)
16-25	(19-28)	y-momentum	E10.0	(E10.0)
26-35	(29-38)	z-momentum	E10.0	(E10.0)
36-45	(39-48)	Deposition time	E10.0	(E10.0)

2.44 DETONATION POINT DATA (E10.0,I5,3E10.0).

Skip this section if columns 76-80 of Card 4 are blank. Otherwise enter one card as follows for each H.E. detonation point.

Columns	Quantity	Format
1-10	Lighting time for detonation point	E10.0
11-15	Material to be lit EQ.0: all H.E. materials are considered	I5
16-25	x-coordinate of detonation point	E10.0
26-35	y-coordinate of detonation point	E10.0
36-45	z-coordinate of detonation point	E10.0

2.45 SHELL-BRICK INTERFACES.

For each interface:

Card 1 (2I5)

Columns	Quantity	Format
1-5	Number of shell nodes	I5
6-10	Number of brick nodes tied to each shell node (maximum of nine)	I5

Cards 2...Number of shell nodes +1
(10I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Shell node, sl	I5	(I8)
6-10	(9-16)	Brick node, n_1	I5	(I8)
11-15	(17-24)	Brick node, n_2	I5	(I8)
.	.	.	.	
.	.	.	.	
.	.	.	.	
.	.	.	.	
46-50	(73-80)	Brick node, n_9	I5	(I8)

The shell brick interface, an extension of the tied surface capability, ties regions of hexahedron elements to regions of shell elements. A shell node may be tied to up to nine brick nodes lying along the tangent vector to the nodal fiber. During the calculation, nodes thus constrained must lie along the fiber but can move relative to each other in the fiber direction. The brick nodes must be input in the order in which they occur, in either the plus or minus direction, as one moves along the shell node fiber.

This feature is intended to tie four node shells to eight node shells or solids; it is not intended for tying eight node shells to eight node solids.

2.46 DISCRETE SPRINGS, DAMPERS, AND MASSES.

Skip this section if INPSD equals zero.

This section provides for the definition of simple node to node translational springs, dampers, and masses. All except MTY=8 are valid for large deflections. Springs enter into the time step calculations, so care must be taken to ensure that at the connections nodal masses are defined and unrealistically high stiffnesses are avoided. Dampers do not enter into the calculation so the time step must be artificially limited for high damping values. Otherwise, instabilities may result.

Card 1 (4I5,E10.0)

Columns	Quantity	Format
1-5	Number of material definitions, (NUMMTDE)	I5
6-10	Number of discrete springs and dampers, (NUMELD)	I5
11-15	Number of discrete masses, (NUMMAS)	I5

Define NUMMTDE discrete material card sets below.

Card 2,4,6,...(3I5)

Columns	Quantity	Format
1-5	Material number (≤ NUMMTDE)	I5
6-10	Material type (MTY): EQ.1: linear elastic EQ.2: linear viscous EQ.3: isotropic elastoplastic EQ.4: nonlinear elastic EQ.5: nonlinear viscous EQ.6: general nonlinear EQ.7: liquid spring isolation EQ.8: three-dimensional mount	I5

Cards 3,5,7,...(10E10.0)

Material Type 1 for Discrete Elements (Linear Elastic)

Columns	Quantity	Format
1-10	Elastic stiffness (force/displacement)	E10.0

Material Type 2 for Discrete Elements (Linear Viscous)

Columns	Quantity	Format
1-10	Damping constant (force/displacement rate)	E10.0

Material Type 3 for Discrete Elements (Isotropic Elastoplastic)

Columns	Quantity	Format
1-10	Elastic stiffness (force/displacement)	E10.0
11-20	Tangent stiffness (force/displacement)	E10.0
21-30	Yield (force)	E10.0

Material Type 4 for Discrete Elements (Nonlinear Elastic)

Columns	Quantity	Format
1-10	Load curve number describing force versus displacement relationship	E10.0

Material Type 5 for Discrete Elements (Nonlinear Viscous)

Columns	Quantity	Format
1-10	Load curve number describing force versus rate-of-displacement relationship	E10.0

Material Type 6 for Discrete Elements (General Nonlinear)

Columns	Quantity	Format
1-10	Load curve number describing force versus displacement relationship for loading	E10.0
11-20	Load curve number describing force versus displacement relationship for unloading	E10.0
21-30	Hardening parameter ($0 < \beta < 1$)	E10.0
31-40	Initial yield force in tension (> 0)	E10.0
41-50	Initial yield force in compression (< 0)	E10.0

Material Type 7 for Discrete Elements (Liquid Spring)

Columns	Quantity	Format
1-10	Linear transition distance	E10.0
11-20	Constant force term	E10.0
21-30	Linear force term	E10.0
31-40	Quadratic force term	E10.0
41-50	Cubic force term	E10.0
51-60	Initial load	E10.0

Columns	Quantity	Format
1-10	Smoothing transition	E10.0
11-20	Force away coefficient	E10.0
21-30	Force away exponent	E10.0
31-40	Force towards coefficient	E10.0
41-50	Force towards exponent	E10.0

Material Type 8 for Discrete Elements (Navy Mounts)

Columns	Quantity	Format
1-10	3D mount model (MTYMOD) EQ.1: HCM-1 EQ.2: 5M10000 EQ.3: SAM-1 EQ.4: Aeroflex EQ.6: General Nonlinear Spring-Dashpot EQ.7: HCM-2 EQ.8: HCM-3 EQ.9: HCM-3 snubber only	E10.0
	Remaining mount inputs depend on MTYMOD:	
	If MTYMOD = 1, complete the card	
11-20	Snubber (1=Yes, 0=No)	E10.0
21-30	Axial gap for compression E10.0	
31-40	Axial gap for tension	E10.0
41-50	Radial gap	E10.0
51-60	Supported weight	E10.0
	If MTYMOD = 2, complete the card	
11-20	Snubber type	E10.0
21-30	Snubber gap	E10.0
31-40	Axial snubber offset	E10.0
41-50	Supported weight	E10.0
51-60	Initial snubber offset, local x	E10.0
61-70	Initial snubber offset, local y	E10.0

	If MTYMOD = 3, complete this and the next card	
11-20	Axial transition point from initial to hardening stiffness	E10.0
21-30	Initial axial stiffness upon loading K1	E10.0
31-40	Axial hardening stiffness upon loading K2	E10.0
41-50	Axial unloading stiffness K3 (K1 < K2 < K3)	E10.0
51-60	Supported weight	E10.0
1-10	Set = 3.	E10.0
11-20	Radial transition point from initial to hardening stiffness	E10.0
21-30	Initial radial stiffness upon loading K1	E10.0
31-40	Radial hardening stiffness upon loading K2	E10.0
41-50	Radial unloading stiffness K3 (K1 < K2 < K3)	E10.0
51-60	Supported weight	E10.0
	If MTYMOD = 6	
11-20	Load curve number for axial force vs. displacement	E10.0
21-30	Load curve number for radial force vs. displacement	E10.0
31-40	Load curve number for axial force vs. velocity	E10.0
41-50	Load curve number for radial force vs. velocity	E10.0
	If MTYMOD = 7, complete the card	
11-20	Snubber (1=Yes, 0=No)	E10.0
21-30	Axial gap for compression E10.0	
31-40	Axial gap for tension	E10.0
41-50	Radial gap	E10.0
51-60	Supported weight	E10.0

	If MTYMOD = 8, complete the card	
11-20	Snubber (1=Yes, 0=No)	E10.0
21-30	Axial gap for compression	E10.0
31-40	Axial gap for tension	E10.0
41-50	Radial gap	E10.0
51-60	Supported weight	E10.0
	If MTYMOD = 9, complete the card	
11-20	Snubber (1=Yes, 0=No)	E10.0
21-30	Axial gap for compression	E10.0
31-40	Axial gap for tension	E10.0

Define NUMELD discrete springs and dampers below.

(4I5,E10.0,3I5) or (4I8,E10.0,3I5) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Discrete Element number	I5	(I8)
6-10	(9-16)	Node n_1	I5	(I8)
11-15	(17-24)	Node n_2	I5	(I8)
16-20	(25-32)	Material number	I5	(I8)
21-30	(33-42)	Scale factor on force (default = 1.0)	E10.0	(E10.0)
31-35	(43-47)	Node n_3 The third node is optional, but recommended if a known radial orientaqtion is desired. Otherwise, the code will choose a radial orientation in the plane at n_1 defined by the element axis n_1- n_2.	I5	(I8)

Define NUMMAS lumped masses.

(I5,E10.0)

Columns	Quantity	Format
1-5	Node number	I5
6-15	Mass	E10.0

2.47 RIGID BODY INERTIAL PROPERTIES.

NOTE: All data must be provided. This data supersedes other input data (e.g. nodal initial velocities).

Card 1 (I5,4E10.0)

Columns	Quantity	Format
1-5	Material number of rigid body	I5
6-15	x-coordinate of center of mass	E10.0
16-25	y-coordinate of center of mass	E10.0
26-35	z-coordinate of center of mass	E10.0
36-45	Translational mass	E10.0

Card 2 (6E10.0)

Columns	Quantity	Format
1-10	I_{xx}, xx component of inertia tensor	E10.0
11-20	I_{xy}	E10.0
21-30	I_{xz}	E10.0
31-40	I_{yy}	E10.0
41-50	I_{yz}	E10.0
51-60	I_{zz}	E10.0

The inertia tensor is defined in the global coordinate system.

Card 3 (6E10.0)

Columns	Quantity	Format
1-10	x-rigid body translational velocity	E10.0
11-20	y-rigid body translational velocity	E10.0
21-30	z-rigid body translational velocity	E10.0
31-40	x-rigid body rotational velocity	E10.0
41-50	y-rigid body rotational velocity	E10.0
51-60	z-rigid body rotational velocity	E10.0

2.48 NONREFLECTING BOUNDARY SEGMENTS.

(6I5,2E10,2I5) or (5I8,2E10,2I5) for LARGE option

Define NNRBS (Card 6, Section 2) cards in this section.

Columns		Quantity	Format	
1-5	(1-8)	Surface segment number	I5	(I8)
6-10	(-)	Increment k	I5	(omit)
11-15	(9-16)	Nodal point n_1	I5	(I8)
16-20	(17-24)	Nodal point n_2	I5	(I8)
21-25	(25-32)	Nodal point n_3	I5	(I8)
26-30	(33-40)	Nodal point n_4	I5	(I8)
31-40	(33-42)	Activation flag for normal waves (on.EQ.0.0, off.ne.0.0) (NNC)		E10.0
41-50	(43-52)	Activation flag for tangential waves (on.EQ.0.0, off.ne.0.0) (NNC)		E10.0
51-55	(53-57)	Specified velocity versus time curve for segment (NNC)	I5	(I5)
56-60	(58-62)	Direction applied velocity acts(NNC) EQ.1: x EQ.2: y EQ.3: z	I5	(I5)

2.49 TEMPERATURE DATA.

(I5,2E10.0,2I5) or (I8,2E10.0,2I8) for LARGE option

Define NUMNP temperature cards in this Section if and only if the thermal effects option is set to -9999.

Columns		Quantity	Format	
1-5	(1-8)	Nodal point number	I5	(I8)
6-15	(9-18)	Scaled temperature	E10.0	(E10.0)
16-25	(19-28)	Base temperature	E10.0	(E10.0)
26-35	(29-33)	Number of load curve that multiplies scaled temperature	I5	(I8)
36-45	(34-38)	Generation increment k	I5	(I8)

(I5,10x,E10.0) or (I8,10x,E10.0) for LARGE option

Define NUMNP temperature cards in this Section if and only if the thermal effects option is set to -2. The reference temperature state is assumed to be a null state with this option. A nodal temperature state, read in below and held constant throughout the analysis, dynamically loads the structure.

Columns		Quantity	Format	
1-5	(1-8)	Nodal point number	I5	(I8)
16-25	(19-28)	Temperature	E10.0	(E10.0)

If nodal points are missing VecDYNA3D will linearly interpolate to find the undefined temperatures. Input in this section will cease to be read when the final nodal point number is encountered.

2.50 1D SLIDELINE DEFINITIONS.

The one-dimensional slidelines (Pelessone). Define NUMSL sets of one-dimensional slidelines.

Columns	Quantity	Format
1-5	Number of slave nodes, NSN	I5
6-10	Number of master nodes, NMN	I5
11-20	External radius of rebar	E10.0
21-30	Compressive strength of concrete	E10.0
31-40	Bond shear modulus	E10.0
41-50	Maximum shear displacement	E10.0
51-60	Exponent in damage curve (Hdmg)	E10.0

Cards 2,...,NSN+1
(2I5) or (2I8) for LARGE option
(Slave Nodes)

Columns		Quantity	Format	
1-5	(1-8)	Slave number EQ.0: the preceding slave number is incremented by 1	I5	(I8)
6-10	(9-16)	Nodal point number	I5	(I8)

Cards NSN+2,...,NSN+NMN+1
(2I5) or (2I8) for LARGE option
(Master Nodes)

Columns		Quantity	Format	
1-5	(1-8)	Slave number EQ.0: the preceding slave number is incremented by 1	I5	(I8)
6-10	(9-16)	Nodal point number	I5	(I8)

2.51 USA WET SURFACE DEFINITION.

If NUSA is nonzero, define NUSA wet surface segment cards.

Columns	Quantity	Format
1-5	Segment number	I5
6-10	wet (1=wet; 0=dry)	I5
11-20	Nodal point n_1	E10.0
21-30	Nodal point n_2	E10.0
31-40	Nodal point n_3	E10.0
41-50	Nodal point n_4	E10.0

The normal should be directed into the USA fluid.

2.52 RESTART TITLE CARD.

(12A6,3X,A5)

Columns	Quantity	Format
1-72	Heading to appear on output	12A6
76-80	Large format option for node number Default is "LARGE" if the number of nodal points exceeds 99999.	A5

A complete input deck is generally not needed to restart VecDYNA3D. The termination time and output plotting intervals can be changed with just the first three cards. Changes to the model or underwater shock analysis calculations with residual damage require the full deck restart. All changes made when restarting will be reflected in subsequent restart dumps. If a restart is made using a complete VecDYNA3D input file, the resulting familied files will be re-initialized (D3PLOT01, etc.) and a new sequence of files will be created.

2.53 RESTART CONTROL CARDS.

Card 1 (3E10.0,6I5)

Columns	Quantity	Format
1-10	New termination time EQ.0.0: termination time remains unchanged	E10.0
11-20	New output printing interval EQ.0.0: output printing interval remains unchanged for time history data	E10.0
21-30	New output plotting interval EQ.0.0: output plotting interval remains unchanged	E10.0
31-35	Number of sliding interfaces to be eliminated (≤ 49)	I5
36-40	Number of materials to be eliminated	I5
41-45	Number of solid element blocks to be eliminated	I5
46-50	Number of beam element blocks to be eliminated	I5
51-55	Number of 4-node shell element blocks to be eliminated	I5
56-60	Number of 8-node thick shell element blocks to be eliminated	I5

Card 2 (E10.0,4I5)

Columns	Quantity	Format
1-10	New time step scale factor EQ.0.0: time step scale factor remains unchanged	E10.0
11-20	Number of changed translational boundary condition codes	I5
21-30	Number of materials for stress initialization. With this option an entire VecDYNA3D input deck is required as part of the restart input. Materials and sliding interfaces can be added to or deleted from the calculation by using this option. In addition, virtually anything can be changed EQ. -1: all materials will be initialized.	I5
21-35	Number of cycles between restart dumps. EQ.0: no change	I5
36-40	Number of cycles between running restart dumps EQ.0: no change	I5
41-45	Flag to shift restart time EQ.0: no change EQ.1: shift restart time to zero	I5

2.54 DELETED SLIDING INTERFACES WITH RESTART.

Skip this section if there are no deleted sliding interfaces.

(16I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Number of first sliding interface to be deleted	I5	(I8)
6-10	(9-16)	Number of second sliding interface to be deleted	I5	(I8)
10-15	(17-24)	Number of third sliding interface to be deleted	I5	(I8)
.	.	.	.	
.	.	.	.	
.	.	.	.	
.	.	.	.	

2.55 DELETED MATERIAL BLOCKS WITH RESTART.

Skip this section if there are no deleted material blocks.

(16I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	Number of first material to be deleted	I5	(I8)
6-10	(9-16)	Number of second material to be deleted	I5	(I8)
10-15	(17-24)	Number of third material to be deleted	I5	(I8)
.	.	.		.
.	.	.		.
.	.	.		.
.	.	.		.

2.56 DELETED SOLID ELEMENT BLOCKS WITH RESTART.

Skip this section if there are no deleted solid elements.

(16I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	First element of first block to be deleted	I5	(I8)
6-10	(9-16)	Last element of first block to be deleted	I5	(I8)
10-15	(17-24)	First element of second block to be deleted	I5	(I8)
16-20	(25-32)	Last element of second block to be deleted	I5	(I8)
.	.	.	.	
.	.	.	.	
.	.	.	.	
.	.	.	.	

2.57 DELETED BEAM ELEMENT BLOCKS WITH RESTART.

Skip this section if there are no deleted beam elements.

(16I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	First element of first block to be deleted	I5	(I8)
6-10	(9-16)	Last element of first block to be deleted	I5	(I8)
10-15	(17-24)	First element of second block to be deleted	I5	(I8)
16-20	(25-32)	Last element of second block to be deleted	I5	(I8)
.	.	.	.	
.	.	.	.	
.	.	.	.	
.	.	.	.	

2.58 DELETED SHELL ELEMENT BLOCKS WITH RESTART.

Skip this section if there are no deleted shell elements.

(16I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	First element of first block to be deleted	I5	(I8)
6-10	(9-16)	Last element of first block to be deleted	I5	(I8)
10-15	(17-24)	First element of second block to be deleted	I5	(I8)
16-20	(25-32)	Last element of second block to be deleted	I5	(I8)
.	.	.	.	
.	.	.	.	
.	.	.	.	
.	.	.	.	

2.59 DELETED THICK SHELL ELEMENT BLOCKS WITH RESTART.

Skip this section if there are no deleted thick shell elements.

(16I5) or (10I8) for LARGE option

Columns		Quantity	Format	
1-5	(1-8)	First element of first block to be deleted	I5	(I8)
6-10	(9-16)	Last element of first block to be deleted	I5	(I8)
10-15	(17-24)	First element of second block to be deleted	I5	(I8)
16-20	(25-32)	Last element of second block to be deleted	I5	(I8)
.	.	.	.	
.	.	.	.	
.	.	.	.	
.	.	.	.	

2.60 CHANGED BOUNDARY CONDITION CARDS WITH RESTART.

(I5,F5.0) or (I8,F5.0) for LARGE option

Skip this section if there are no changed translational boundary condition codes.

Columns		Quantity	Format	
1-5	(1-8)	Nodal point number	I5	(I8)
6-10	(9-16)	New boundary condition code	F5.0	(F5.0)

2.61 MATERIAL INITIALIZATION WITH RESTART (2I5).

Skip this section if the number of materials to be initialized is zero or equal to -1.

Columns	Quantity	Format
1-5	Material identification number used in dump file	I5
6-10	Material identification number used in new input file	I5

Repeat as above for each material to be initialized. Include an entire input description file (omit only the Title Card), which contains all the changes for the restarted problem. Note that values in this portion of the restart file override previously specified values. Termination time on Card 2 above is overridden by the value on the normal VecDYNA3D control cards defined below.

2.62 LOAD CURVE CARDS WITH RESTART.

Redefine the number, NRDLC, of load curve sets specified. Repeat the following cards for redefined each set:

Card 1 (2I5)

Columns	Quantity	Format
1-5	Load curve number of redefined curve	I5
6-10	Number of points in load curve (must not change), NPTS	I5

Card 2,...,NPTS+1 (2E10.0)

Columns	Quantity	Format
1-10	Time	E10.0
11-20	Load or function value	E10.0

SECTION 3

USA PROCESSOR USER INSTRUCTIONS

The FLUMAS component of the underwater shock analysis code constructs the fluid mass matrix for a structure submerged in an infinite, inviscid, incompressible fluid by the boundary element technique. It also generates fluid mesh data and a set of transformation coefficients that relate the structural and fluid degrees of freedom on the wet surface. The code has the capability to treat structures containing both surface-of-revolution (sor) and general-geometry (gen) components. The code can construct the fluid mass matrix for both quarter and half models with arbitrarily assigned symmetry or antisymmetry conditions, and can simulate the two-dimensional plane strain behavior of long cylinders. The presence of a free surface in the vicinity of the submerged structure can also be accounted for in the fluid mass matrix. A very useful diagnostic tool contained within the code is the ability to solve the fluid boundary mode eigenvalue problem.

The AUGMAT component of the underwater shock analysis code accepts data from the fluid mass matrix processor and the structural analyzer to construct the specific constants and arrays that are used in the staggered solution procedure for the transient response analysis of submerged structures.

The TIMINT component of the underwater shock analysis code conducts a step-by-step direct numerical time integration of the governing equations of submerged structures exposed to spherical shock waves of arbitrary pressure profile and source location. The fluid equations utilize the well-known doubly asymptotic approximation (DAA) while the structure itself may be treated by a variety of linear or nonlinear program modules that carry out the spatial analysis at each time step. The code uses the staggered solution procedure wherein the structural response equations and the fluid response equations are solved separately at each time step through extrapolation of the terms which couple the two systems.

The CFA component of the underwater shock analysis code implements an explicit, bilinear acoustic fluid formulation to treat any combination of internal and external fluids. External fluids are truncated at some outer boundary with the first-order DAA formulation. The processor itself is largely invisible to the user. The definition of the fluid continuum and its coupling are conveyed to USA on the databases cavnam and facnam.

3.1 INPUT DATA RECORDS FOR FLUMAS PROCESSOR.

All input data can be typed in a free field format with a blank space or comma used to separate the distinct entries. However, any individual piece of data must not be longer than 10 characters.

GENERAL PROBLEM DEFINITION (SUBROUTINE AMINPT):

72 COLUMN ALPHANUMERIC TITLE

FLUNAM	GEONAM	GRDNAM	DAANAM
PRTGMT	PRTTRN	PRTAMF	CALCAM
EIGMAF	TWODIM	HAFMOD	QUAMOD
PCHCDS	NASTAM	STOMAS	STOINV
FRWTFL	FRWTGE	FRWTGR	FRESUR
RENUMB	STOGMT	ROTGEO	ROTQUA
PRTCOE	STRMAS	SPHERE	ROTSYM
OCTMOD	CAVFLU	FRWTFV	INTCAV

IF CAVFLU = .TRUE. READ THE FOLLOWING RECORD

CAVNAM FACNAM

IF FRWTGR = .FALSE. OR FRWTFV = .FALSE. READ THE FOLLOWING RECORD, SKYNOM VERSION ONLY

MAINKY

NSTRC	NSTRF	NGEN	NGENF
NBRA	NCYL	NCAV	

IF CAVFLU = .TRUE. READ THE FOLLOWING RECORD

NFVNC NFVNF

IF NBRA NOT = 0 INCLUDE THE FOLLOWING THREE RECORDS

NHAS NHAF NHAI NFUN ITRG
NSEG(I), I=1,NBRA
NCIR(I), I=1,NBRA

RHO CEE

IF EIGMAF = .TRUE. INCLUDE THE FOLLOWING RECORD

NVEC

IF HAFMOD = .TRUE. INCLUDE THE FOLLOWING TWO RECORDS

CQ(I), I=1,2
DHALF CXHF CYHF CZHF

IF QUAMOD = .TRUE. INCLUDE THE FOLLOWING RECORD

CQ(I), I=1,4

IF QUAMOD = .TRUE. AND NBRA NOT = 0 INSERT THIS RECORD

DHALF CXHF CYHF CZHF

IF OCTMOD = .TRUE. INCLUDE THE FOLLOWING TWO RECORDS

CQ(I), I=1,4
DHALF CXHF CYHF CZHF

IF FRESUR OR CAVFLU = .TRUE. INCLUDE THE FOLLOWING TWO RECORDS

DEPTH CXFS CYFS CZFS
PATM GRAVAC

IF ROTGEO = .TRUE. INCLUDE THE FOLLOWING TWO RECORDS

GEOTRN(I), I=1,3
GEOANG(I), I=1,3

IF ROTQUA = .TRUE. INCLUDE THE FOLLOWING TWO RECORDS

QUATRN(I), I=1,3
QUAANG(I), I=1,3

IF NCYL NOT = 0 READ THE FOLLOWING RECORD

NSHIFT

<u>STRUCTURAL NODE COORDINATES (SUBROUTINE READST):</u>

IF NSTRC NOT = 0 INCLUDE THE FOLLOWING RECORDS

NSEQ	NS	XC	YC	ZC)	
.	.	.	.	.)	TOTAL = NSTRC
.	.	.	.	.)	

<u>FLUID VOLUME NODE COORDINATES (SUBROUTINE READFV):</u>

IF NFVNC NOT = 0 INCLUDE THE FOLLOWING RECORDS

NVOL	NS	XF	YF	ZF)	
.	.	.	.	.)	TOTAL = NFVNC
.	.	.	.	.)	

<u>STRUCTURE/FLUID CONNECTIVITIES (SUBROUTINE NODTAB):</u>

IF CAVFLU = .TRUE. READ THE FOLLOWING RECORDS

NUMCON

IF NUMCON NOT = 0 READ THE FOLLOWING RECORDS

NSTC	NFLC)	
.	.)	TOTAL = NUMCON
.	.)	

GENERAL ELEMENT DEFINITION (SUBROUTINE GENELM):

IF NGENF NOT = 0 READ THE FOLLOWING RECORDS

NSRADI

IF NSRADI NOT = 0 READ THE FOLLOWING RECORDS

RAD1	RAD2	JBEG	JEND	JINC)	
.	.	.	.	.)	TOTAL = NSRADI
.	.	.	.	.)	

NSORDR

IF NSORDR NOT = 0 READ THE FOLLOWING RECORDS

NORD	JBEG	JEND	JINC)	
.	.	.	.)	TOTAL = NSORDR
.	.	.	.)	

IF NGEN NOT = 0 READ THE FOLLOWING RECORDS

NEL	NC	NN	KURV	KTRN)	
NODE(I), I=1,NC				)	
				)	
IF NN NOT = 0 READ THE FOLLOWING RECORD				)	
				)	
ITEM(I), I=1,NN				)	TOTAL NUMBER OF
				)	SETS = NGEN
IF KURV = 2 READ THE FOLLOWING RECORD				)	
				)	
RAD1 RAD2 ECCEN				)	
				)	
IF KTRN NOT = 0 READ THE FOLLOWING RECORD				)	
				)	
TRAN(I), I=1,NC+NN				)	

IF SPHERE = .TRUE. READ THE FOLLOWING RECORD

SPHRAD

CYLINDRICAL SURFACE GENERAL ELEMENTS (SUBROUTINE CYLGEO):

IF NCYL NOT = 0 READ THE FOLLOWING RECORDS FOR EACH AXIAL SEGMENT

NTCY	KFUN	KROT	KARC		
NCRC	NLAST	NSTART	NDAX1	NDCR	NDAX2
RAD	AXL1	AXL2	THETS	THETF	AXL3

IF KROT NOT = 0 READ THE FOLLOWING TWO RECORDS

CYLTRN(I), I=1,3
CYLANG(I), I=1,3

SURFACE-OF-REVOLUTION ELEMENT DEFINITION (SUBROUTINE SORINP):

IF NBRA NOT = 0 READ THE FOLLOWING RECORDS FOR EACH SOR BRANCH

N1 N2 R1 R2 NSET

IF N1 = N2 READ THE FOLLOWING RECORD

N3

IF NSET = 1 OMIT THE FOLLOWING RECORD

N1 N2 R1 R2 ISEG)
. . . . .) TOTAL = NSET
. . . . .)

STRUCTURAL NODE RENUMBERING (SUBROUTINE AMGEOM):

IF RENUMB = .TRUE. READ THE FOLLOWING RECORDS

NUMCHG
NODOLD NODNEW)
. .) TOTAL = NUMCHG
. .)

ROTATIONALLY SYMMETRIC FLUID MESH (SUBROUTINE AXISYM):

IF ROTSYM = .TRUE. READ THE FOLLOWING RECORDS

X1 Y1 Z1
X2 Y2 Z2
MHAR
DANG

DEFINITION OF INPUT PARAMETERS

Input variable names given below are generally those which are also used in the coding and the variable types correspond to standard fortran usage:

A - alphanumeric
E - floating point
F - fixed point
I - integer
L - logical

Variable	Type	Description
FLUNAM	A	name of permanent mass storage file that will contain the fluid mass matrix.
GEONAM	A	name of permanent mass storage file that will contain the fluid mesh geometry and fluid-structure transformation data
GRDNAM	A	name of permanent mass storage file that contains the global coordinates of the structural grid points. for the stags structural code this file will also contain the element connectivity data if it is the fortran file created by stags1 on unit 3. the element connectivity will also be in this file if it is a gal (global access library) database created by either the stagal processor (for stags) or nassky (for nastran). in this case frwtgr must be false
DAANAM	A	name of permanent mass storage file that will contain the manipulated daa form of the fluid mass matrix
PRTGMT	L	true if fluid mesh geometry data is to be listed, otherwise false
PRTTRN	L	true if fluid-structure transformation data is to be listed, otherwise false
PRTAMF	L	true if fluid mass matrix is to be listed, otherwise false in which case only the diagonal terms are printed
CALCAM	L	true if the fluid mass matrix is to be computed, otherwise false and the run will terminate after the fluid mesh geometry data has been processed. use a value of true only after debugging of the geometry data has been completed
EIGMAF	L	true if eigenvalues and eigenvectors of the fluid boundary mode problem are desired, otherwise false. the presence of negative eigenvalues is an indication that the fluid mesh is in error, hence this can be an important debugging tool
TWODIM	L	true if a two dimensional plane strain fluid mass matrix is required, otherwise false. the z direction must be perpendicular to the plane of the fluid model. if this is not so a temporary or permanent coordinate rotation can be applied for computation of the matrix (see rotqua or rotgeo). if general fluid elements are to be defined by hand for a two dimensional problem, the input order of the corner nodes is subject to a minor restriction (see node). wet-surface elements obtained from a stags file must be re-ordered as the default numbering scheme used by stags begins with the axial direction (see nsordr)
HAFMOD	L	true if the fluid mesh input geometry corresponds to a half model, otherwise false. the variables dhalf, cxhf, cyhf, and czhf are used to define the location and orientation of the symmetry plane
QUAMOD	L	true if the fluid mesh input geometry corresponds to a quarter model, otherwise false. the xz and yz planes are considered to be the planes of symmetry of the model by default. if necessary a coordinate rotation and/or translation can be applied to satisfy this requirement (see rotqua below). if ncyl is not equal to zero such a transformation must be used in conjunction with the quarter model (see also krot below). this transformation will not affect the orientation of the fluid mesh reference axes in subsequent usa processing
PCHCDS	L	true if the diagonal generalized area matrix is to be punched out on cards for input to nastran, otherwise false

Variable	Type	Description
NASTAM	L	true if the fluid mass matrix or its manipulated form which appears in the daa equation is to be put in the permanent file designated by flunam in a format which can be read by nastran, otherwise false
STOMAS	L	true if the fluid mass matrix itself is to be put in permanent storage, otherwise false
STOINV	L	true if the manipulated form of the fluid mass matrix which appears in the daa equation is to be put in permanent storage, otherwise false. this matrix consists of the inverted fluid mass matrix that has been pre- and post-multiplied by the diagonal fluid element area matrix and then multiplied by both the mass density and the speed of sound of the fluid
FRWTFL	L	true if the permanent file containing the fluid mass matrix or its manipulated form is to be created by buffered, unformatted fortran write statements, otherwise false and dmgasp will create the file
FRWTGE	L	true if the permanent file containing the fluid mesh geometry is to be created by buffered, unformatted fortran write statements, otherwise false and dmgasp will create the file
FRWTGR	L	true if the permanent file containing structural grid point coordinates has been created by buffered, unformatted fortran write statements, otherwise false in which case it is assumed that dmgasp was used to create the file. consult a listing of the subroutine readst for the file structure that is expected which differs for the two possible cases. this file must exist for interfacing with stags
FRESUR	L	true if free surface effects are to be included in the fluid mass matrix, otherwise false. the variables depth, cxfs, cyfs, and czfs are used to define the location and orientation of the free surface
RENUMB	L	true if some renumbering of the structural node numbers must be carried out after the fluid-structure transformation data has been generated, otherwise false. this option is important if the use of a particular structural node number is convenient to define the fluid mesh but, instead, a nearby structural node should be used for force application during the underwater shock analysis time integration run. this case is particularly important if the two points in question are joined by a rigid link and the structural point originally used to define the fluid mesh is eliminated from the stiffness matrix by a constraint equation. without the use of this option the appropriate force would not be applied to the equations of motion
STOGMT	L	true if the fluid mesh geometry and fluid-structure transformation data is to put in permanent storage, otherwise false
ROTGEO	L	true if the fluid mesh geometry is to be referred to a set of global coordinate axes which is different from that of the basic input data for all subsequent usa processing (see geoang and geotrn), otherwise false
ROTQUA	L	true if the fluid mesh geometry is to be referred to a set of global coordinate axes which is different from that of the basic input data only for computation of the fluid mass matrix (see quaang and quatrn), otherwise false. this option is to be used if a quarter model is required and the input data reference axes do not coincide with the default symmetry axes. this feature can also be used in conjunction with the two dimensional plane strain model as well (see twodim)

Variable	Type	Description
PRTCOE	L	true if the b and c matrices are to be printed for some diagnostic reason, otherwise false under normal operating conditions. these matrices are full and generally nonsymmetric. the product b*cinv is the principal computation that is required to form the fluid mass matrix (see deruntz and geers, added mass computation by the boundary integral method, int j num meth, vol 12, 1978, pp 531-550)
STRMAS	L	true if the input fluid mesh geometry is to be restructured so that the fluid mass matrix will be found relative to the structural nodes. this capability is operational for a structural model with a finite volume but will not treat nodes on the edges of a structure if there are no elements around the corner, e.g., a flat plate all by itself. this feature is operational only for fluid models with general elements and will not treat those with sor elements
SPHERE	L	true if the model is a sphere. in this case the global coordinates and direction cosines of the outward unit normal are adjusted so that they are analytically exact in contrast to the approximations made in a finite element model with not quite planar quadrilaterals. the radius of the daa boundary is read later (see sphrad). set this variable to false for non-spherical surfaces
ROTSYM	L	true if the model is a circumferential segment of a rotationally symmetric surface mesh and consists of general elements only, otherwise false
OCTMOD	L	true if the model is an octant or eighth model, otherwise false. this capability uses internal routines for both the half and quarter model options by considering it as a half of a quarter model. the user must invoke quarot or quageo if appropriate and the symmetry options in the array cq for the quarter model still apply here, however only symmetry conditions are currently allowed in the half model direction.
CAVFLU	L	true if the cavitating fluid analyzer (cfa) will be used with usa-stags in the present model, otherwise false
FRWTFV	L	true if the permanent file containing fluid volume grid point coordinates has been created by buffered, unformatted fortran write statements, otherwise false in which case it is assumed that fluset was used to create the file as a gal (global access library) database
INTCAV	L	true if the cavitating fluid analyzer (cfa) will be used with usa-stags in the present model with only internal fluid volume elements and the daa boundary on the wet surface of the structure, otherwise false
CAVNAM	A	name of permanent mass storage file that contains the global coordinates of the fluid volume grid points
FACNAM	A	name of permanent mass storage file that contains the element connectivities of the daa and structure boundaries when fluid volume elements are used with the cavitating fluid analyzer. if frwtfv is true this is a separate file from cavnam but if frwtfv is false then both sets of data are in the same file
MAINKY	A	identifying name to be associated with the datasets in the gal database containing the structural geometry and element connectivity, maximum of 16 characters. required for skynom version only. (see grdnam)
NSTRC	I	number of structural node or grid points whose global coordinates are to be read from input data records. at the very least the sum of nstrc and nstrf (see below) must include

Variable	Type	Description
		all the wet nodes, ie., those lying on the fluid-structure contact boundary. if the ultimate purpose of this run is to conduct an underwater shock analysis with the usa code for the structure in question then it is advisable to include in the input to this processor all of the internal or dry structural node points as well in order to facilitate post processing of the transient response analysis for the dry structure. this number may also include additional node points that are not part of the structural model but which are necessary to define the fluid mesh. however such additional nodes should appear last as they are not required by any other usa processor and are therefore ultimately deleted
NSTRF	I	number of structural node or grid points whose global coordinates are to be read from a permanent file (see grdnam). additional node points that are not part of the structural model are not permitted in this data set if actual structural node point data appears also on input records. this is due to the fact that the file data is read first, then the input records, and any additional non-structural node points must appear last in the grid point list. this file must always be referenced when interfacing with stags
NGEN	I	number of general fluid degrees of freedom whose associated elements cannot be formed by an automatic mesh generation procedure
NGENF	I	if this is not a usa-stags-cfa analysis, ie., without any fluid volume elements, this is the number of general fluid elements whose corner point connectivity definitions are already available in the permanent file containing the global coordinates of the structural node points (see grdnam). such elements will always be in a one to one correspondence with the structural elements since the grdnam file contains the actual connectivity data of the structural elements. two forms of this feature are available at this time. the first is for the interface with the stags structural code using the fortran file created by stags1 on unit 3. in this form the user must ensure that any dry structure stags shell or element units appear after all the wet surface shell or element units so that the first `ngenf' elements are wet and any others following on the grdnam file are dry. the second option assumes that the grdnam file is a gal (global access library) database. such a database is created for stags models by the stagal processor while nastran models use the nassky processor. in either case a record group is present in the database that specifies whether any particular element is wet or dry, hence they may be mixed in any order if this is a usa-stags-cfa analysis that uses fluid volume elements, then this parameter is the total number of daa and structural `face' elements in contact with fluid volume elements whose corner point connectivity definitions are available in the fluid `face' file (see facnam) a negative sign can be assigned to this variable to indicate that daa elements are available in the data file but, overlaying fluid elements that are not in a one to one correspondence will be defined through detailed general input (see ngen). this capability is primarily related to the usa-dyna code
NBRA	I	number of distinct surface of revolution axes or branches
NCYL	I	number of general fluid control points which lie on a right circular cylindrical surface whose associated rectangular elements cover the entire lateral surface. such elements can be formed by an automatic mesh generation scheme which is embedded in the code. structural grid point coordinates need not be input in this case unless dictated by other circumstances
NCAV	I	total number of outside and inside structural boundary elements in contact with fluid volume elements
NFVNC	I	number of fluid volume node or grid points whose global coordinates are to be read

Variable	Type	Description
		from input records
NFVNF	I	number of fluid volume node or grid points whose global coordinates are to be read from a permanent file (see cavnam)
NHAS	I	starting circumferential harmonic for surface of revolution elements
NHAF	I	final circumferential harmonic for surface of revolution elements
NHAI	I	increment to be applied in assigning circumferential harmonics in the range from nhas to nhaf
NFUN	I	number of trigonometric functions that will be used in assigning surface of revolution fluid degrees of freedom. permissible values are: 1 - either sine or cosine will be used according to value of itrg described below 2 - both sine and cosine functions will be used
ITRG	I	if nfun = 1 itrg designates the particular trigonometric function to be used for surface of revolution fluid degrees of freedom. allowable values are: 1 - cosine function is used 2 - sine function is used
NSEG	I	number of surface of revolution segments along any particular axis or branch
NCIR	I	number of sub-elements around the circumference of a surface of revolution branch. under normal conditions use a value of zero and the code will choose an appropriate value based upon the aspect ratio of the sub-element. a minimum of twelve (12) is allowed and ncir is always a multiple of four (4). use a non-zero value only under special circumstances and adhere to these guidelines
RHO	E,F	fluid mass density
CEE	E,F	fluid speed of sound
NVEC	I	number of fluid boundary mode eigenvectors desired. these are ordered starting with the lowest order modes first. if all the modes are desired the user can just set nvec to 1000 and the code will automatically reduce this number to the order of the fluid mass matrix. this is convenient when the model contains sor elements for several harmonics and/or branches and the user does not want to spend time counting up the total. this is recommended only for small or intermediate size problems. for large problems printing of only the first 10 eigenvectors is recommended. as it is only the first few are generally useful to verify symmetries or other features of the model. the first one is always a breathing type mode unless the fluid model consists solely of beam type sor elements
CQ	E,F	used for fluid mesh models with planes of symmetry. cq takes on the value of either plus or minus one to denote symmetric or antisymmetric flow conditions in each fluid region including those that are not explicitly contained in the model. for a quarter model 4 values are required, one for each quadrant. only 2 values are necessary for a half model

Variable	Type	Description
DHALF	E,F	magnitude of perpendicular distance from the origin of coordinates to the plane of symmetry for a half model
CXHF	E,F	direction cosine of a unit vector normal to the plane of symmetry for a half model and pointing out of the fluid region explicitly contained in the model. it must be relative to the global cartesian coordinates of the fluid mesh. if any coordinate rotations are applied to the fluid mesh geometry (see rotgeo and rotqua) this quantity will also be transformed
CYHF	E,F	direction cosine of a unit vector normal to the plane of symmetry for a half model and pointing out of the fluid region explicitly contained in the model. it must be relative to the global cartesian coordinates of the fluid mesh. if any coordinate rotations are applied to the fluid mesh geometry (see rotgeo and rotqua) this quantity will also be transformed
CZHF	E,F	direction cosine of a unit vector normal to the plane of symmetry for a half model and pointing out of the fluid region explicitly contained in the model. it must be relative to the global cartesian coordinates of the fluid mesh. if any coordinate rotations are applied to the fluid mesh geometry (see rotgeo and rotqua) this quantity will also be transformed
DEPTH	E,F	magnitude of perpendicular distance from the origin of coordinates to the plane of the free surface
CXFS	E,F	direction cosine of a unit vector normal to the plane of the free surface and pointing out of the fluid region explicitly contained in the model. it must be relative to the global cartesian coordinates of the fluid mesh. if any coordinate rotations are applied to the fluid mesh geometry (see rotgeo and rotqua) this quantity will also be transformed
CYFS	E,F	direction cosine of a unit vector normal to the plane of the free surface and pointing out of the fluid region explicitly contained in the model. it must be relative to the global cartesian coordinates of the fluid mesh. if any coordinate rotations are applied to the fluid mesh geometry (see rotgeo and rotqua) this quantity will also be transformed
CZFS	E,F	direction cosine of a unit vector normal to the plane of the free surface and pointing out of the fluid region explicitly contained in the model. it must be relative to the global cartesian coordinates of the fluid mesh. if any coordinate rotations are applied to the fluid mesh geometry (see rotgeo and rotqua) this quantity will also be transformed
PATM	E,F	ambient atmospheric pressure that is used ultimately to test for bulk cavitation in the underwater shock analysis
GRAVAC	E,F	acceleration due to gravity
GEOTRN	E,F	x, y, and z direction translations permanently applied to fluid node points. will be applied after rotation of coordinates (see geoang below)
GEOANG	E,F	eulerian angles of rotation used to describe a permanent coordinate transformation for the fluid mesh geometry. three values expressed in degrees are required. the first is the rotation about the original x axis, the second is the rotation about the line coincident with the current orientation of the original y axis after the first rotation, and finally the third is the rotation about the line coincident with the current orientation of the original z axis after the first two rotations. although this method may be somewhat cumbersome for arbitrary spatial orientations almost all cases of practical interest will deal only with

Variable	Type	Description
		values of 0, 90, and/or 180 degrees
QUATRN	E,F	x, y, and z direction translations temporarily applied to fluid node points. will be applied after rotation of coordinates (see quaang below)
QUAANG	E,F	eulerian angles of rotation used to describe a temporary coordinate transformation for the fluid mesh geometry (see geoang above for precise definition). if a quarter model is required and the mesh has been generated automatically for a cylindrical surface bounded by 0 and 180 degrees then the appropriate angles to use here would be 90, 90, and 0
NSHIFT	I	a parameter that is added to the value of nlast (see below) in the numbering of fluid elements automatically generated for cylindrical surfaces. this option is useful if a fluid mesh has been constructed with both gen elements and cylindrical surface elements and then gen elements are removed or added later in a remodeling effort. since gen elements appear first in the element list the use of this parameter eliminates any need to change the numbering scheme on data records for cylindrical surface elements. nshift may be positive, negative, or zero
NSEQ	I	external structural grid point number as assigned by the user. these need not be in any particular order other than that required by the users structural code. Stags uses a sequential numbering scheme
NSI		indicator to denote type of coordinate system grid point data is referred to. Allowable values are: 0 - global cartesian 1 - polar cylindrical, axis in global x direction 2 - polar cylindrical, axis in global y direction 3 - polar cylindrical, axis in global z direction
XC	E,F	cartesian coordinate of structural grid point if ns = 0. if ns = 1, 2, or 3 this is the radial coordinate in a polar cylindrical system
YC	E,F	cartesian coordinate of structural grid point if ns = 0. if ns = 1, 2, or 3 this is the circumferential coordinate in a polar cylindrical system. the angle must be expressed in degrees and be measured from the y, z, or x axis respectively according to whether ns is equal to 1, 2, or 3
ZC	E,F	cartesian coordinate of structural grid point if ns = 0. if ns = 1, 2, or 3 this is the axial coordinate in a polar cylindrical system
NVOL	I	external fluid volume grid point number assigned by the user. at this time all nodes must be sequentially ordered
XF	E,F	cartesian coordinate of fluid volume grid point if ns = 0. if ns = 1, 2, or 3 this is the radial coordinate in a polar cylindrical system
YF	E,F	cartesian coordinate of fluid volume grid point if ns = 0. if ns = 1, 2, or 3 this is the circumferential coordinate in a polar cylindrical system. the angle must be expressed in degrees and be measured from the y, z, or x axis respectively according to whether ns is equal to 1, 2, or 3

Variable	Type	Description
ZF	E,F	cartesian coordinate of fluid volume grid point if ns = 0. if ns = 1, 2, or 3 this is the axial coordinate in a polar cylindrical system
NUMCON	I	number of data pairs relating structural nodes connected to fluid volume nodes that have not been preassigned by previous mesh generation software
NSTC	I	structural node point connected to fluid volume node nflc
NFLC	I	fluid volume node connected to structural node point nstc
NSRADI	I	number of data sets used to define the radii of curvature of fluid elements whose corner point connectivity is available in the structural node point file (see ngenf, grdnam). if a curvature corrected second order doubly asymptotic approximation is to be used in the transient response analysis this data is absolutely required. See the augmat manual for additional details
RAD1	E,F	radius of curvature of fluid element in direction from first corner point to second corner point. infinite radius is assumed if zero is entered, or, if a value greater than or equal to 10000 is used
RAD2	E,F	radius of curvature of fluid element in direction perpendicular to side joining first corner point and second corner point. infinite radius is assumed if zero is entered, or, if a value greater than or equal to 10000. is used
JBEG	I	first of one or more fluid elements having a common value or attribute
JEND	I	last of one or more fluid elements having a common value or attribute
JINC	I	increment to be applied in assigning a common value or attribute to a set of fluid elements in the range from jbeg to jend
NSORDR	I	number of data sets used to define whether or not the corner point connectivity of a fluid element read from the structural node file is to be cyclically permuted once. this is required only for two dimensional models because the logarithmic potential for this case involves integrals based upon the arc length of the elements around the circumference. the convention used here to determine these quantities assumes that the direction from the first node to the second node specified in the element connectivity is circumferential. if the structural code in use creates an axial direction for the first two nodes then this option must be exercised. the default stags node order is incorrect for quadrilateral elements in two dimensional problems and must always be reordered. no general guidelines are available for all other codes linked with usa so please be extremely careful in checking the nodal connectivities in two dimensional problems
NORD	I	a value of zero indicates that the corner point ordering contained in the structural node file for the present element is acceptable as is. a value of one (1) means to cyclically permute the ordering once in a clockwise direction. a value of minus one (-1) means to cyclically permute the ordering once in a counter clockwise direction
NEL	I	general fluid element index which runs from ngenf + 1 to ngenf + ngen in sequential order
NC	I	number of corner points of general fluid element, currently restricted to the values 3 or 4. see fluid element library. the corner points will usually participate in the fluid-

Variable	Type	Description
		structure transformation
NN	I	number of additional structural points associated with a particular general fluid element, currently having permissible values of 0, 1, 2, 3, and 5 if ktrn = 0 (see below and fluid element library). if ktrn is not equal to zero then it may have any value up to 12 for rectangles and 13 for triangles. these additional points always participate in the fluid-structure transformation. it is extremely important to the underwater shock analysis that all wetted structural nodes located within and on the borders of the fluid element be included in nn even if the case ktrn not equal to zero must be invoked
KURV	I	fluid element curvature flag. acceptable values are: 0 - flat element 1 - curved element, code will determine average curvature of element from neighbor point locations. do not use this option if nn = 0 2 - curved element, user must input principle radii of curvature. if either radius is set to 10000 or greater then its associated curvature will be set to zero if a curvature corrected second order doubly asymptotic approximation is to be used in the transient response analysis this data is absolutely required. see the augmat manual for additional details
KTRN	I	should have the value of zero under normal circumstances when the fluid-structure transformation coefficients are computed by the code. if ktrn is nonzero then these coefficients are determined by hand for the element in question and must be read as input data. this must be done if the element does not fit any of the standard patterns in the fluid element library. A discussion of how to do this in an approximate fashion is given below (see tran)
NODE	I	node point numbers of fluid element corner points taken in counter clockwise direction. in general the side defined by the first two corner points should be roughly oriented in the direction of one of the principal axes of the element so as to keep the product of inertia of the element small relative to its principal moments of inertia. if this rule is not followed it is possible that the fluid - structure transformation array for the element will be ill conditioned. assign a negative value to any node number that is not part of the structural finite element model so they will not participate in the fluid - structure transformation. at present such points can only be used in conjunction with 6 - node quadrilaterals. see fluid element library. if twodim is true, the line segment joining the first point to the second point must lie in the plane of the cross section and not be oriented in the axial direction
ITEM	I	node point numbers of fluid element neighbor points again taken in counter clockwise order starting from first corner point. any interior points must appear last. see fluid element library
ECCEN	E,F	provides a means of shifting the fluid control point out of the plane of the structural node points to allow for a finite plate or shell thickness. generally used to define separate fluid elements on opposite sides of a surface. a positive value indicates an eccentricity in the direction of the outward unit normal vector. this option may be used only with kurv equal to 2 at this time. when defining two fluid elements on opposite sides of a surface the first and second node numbers input for one element (see node) should be the second and first node numbers respectively for the other element. in this way the local coordinate system for each element is referred to the same baseline thus preserving a desired symmetry in the calculations

Variable	Type	Description
TRAN	E,F	hand determined coefficients of the fluid-structure transformation array that must be read as input data. the most convenient way of generating these coefficients is to first break the element into sub-elements such as triangles or rectangles such that every structural node is a corner point for one or more sub- elements.the weighting coefficients for triangles and rectangles are one-third and one-fourth respectively and represent the percentage of fluid pressure force on the sub-element that is transmitted to any particular corner point. the fluid- structure transformation coefficient for any particular structural node is then expressed as a sum over the sub-elements that couple with the node in question. the contribution to this sum from each sub- element is just the weighting coefficient of the sub-element times the area of the sub-element divided by the total area of the element. note that the sum of the fluid-structure transformation coefficients for any fluid element must total unity. if the fluid element has a non-structural point as a corner follow the above process anyway and then add the resulting coefficient for the point in question to that for its nearest structural node. if necessary the contribution could even be divided between two or more node points. once computed, the order of input to the code must agree with the order taken first by the corner point node numbers (see node) and then by the neighbor point node numbers (see item) consecutively
SPHRAD	E,F	true radius of daa boundary for discrete element sphere model
NTCY	I	number of structural node points that couple with a curved rectangular fluid element which is to be automatically formed for an axial segment of a right circular cylindrical surface. available options are: 1 - structural node will be coincident with fluid node point (centroid of fluid element) 2 - structural nodes will be on midpoint of curved sides 4 - structural nodes will be at corners 6 - fluid element will overlap two (2) structural elements. variable kfun below also required in this case 9 - fluid element will overlap four (4) structural elements, two in the axial direction and two in the circumferential direction
KFUN	I	describes manner in which a six node rectangular fluid element overlays two rectangular structural elements. Permissible values are: 1 - configuration consists of two structural elements in axial direction 2 - configuration consists of two structural elements in circumferential direction If there are no six node elements in the fluid model this variable can be any integer and it will have no influence
KROT	I	if krot = 0 the z direction will be taken as the axis for automatically generated elements over a cylindrical surface. if krot is not equal to zero a rotation of axes will be performed (see cylang). a coordinate translation can also be performed if required (see cyltrn)
KARC	I	a value of zero used under normal conditions indicates that the area associated with automatically generated cylindrical surface elements is to be calculated using the chord which agrees with what most structural finite element codes assume. a value other than zero will specify that the arc length is to be used instead. the difference between these two cases is generally very small for any reasonable circumferential spacing of the elements. the latter can generate a slightly more accurate fluid mass matrix however the

Variable	Type	Description
		former can give a slightly better structural response calculation
NCRC	I	number of circumferential general elements to be formed automatically for an axial segment of a right circular cylindrical surface. a negative sign on ncrc will imply that the fluid elements are to be on the inside surface of the cylinder
NLAST	I	number of last fluid element in surface mesh which precedes the input for this axial segment. nlast can have the value of zero if required
NSTART	I	number of structural grid or node point at bottom left hand corner of the first of this set of circumferential general fluid elements. if ntcy = 2 this is the node at the midpoint of the left hand side
NDAX1	I	increment to be applied to nstart in designating the number of the corresponding structural node at the first row of circumferential structural nodes to the right of nstart in the axial direction
NDCR	I	increment to be applied to nstart in designating the number of the corresponding structural node at the first row of axial structural nodes above nstart in the circumferential direction. for the case ntcy = 6 with kfun = 2, or ntcy = 9 it is assumed that ndcr is the same for each circumferential increment
NDAX2	I	increment to be applied to nstart + ndax1 in designating the number of the corresponding structural node at the second row of circumferential structural nodes to the right of nstart in the axial direction. this case is characterized by ntcy = 6 with kfun = 1, or ntcy = 9. Otherwise ndax2 can be set to zero
RAD	E,F	radius of circular cylindrical surface
AXL1	E,F	axial coordinate of the first row of structural nodes in the circumferential direction that couple with a particular set of cylindrical surface general elements. this row will form the left axial boundary of the set of fluid elements
AXL2	E,F	axial coordinate of the second row of structural nodes in the circumferential direction that couple with a particular set of cylindrical surface general elements. this row will form the right axial boundary of the set of fluid elements if ntcy = 2, ntcy = 4, or ntcy = 6 with kfun = 2. if ntcy = 6 with kfun = 1, or ntcy = 9 this row will lie within the interior of the fluid element and the structural nodes at this location will be considered as neighbor points in the fluid structure transformation array
THETS	E,F	angle in degrees that specifies the starting boundary for a set of general elements around the partial circumference of a right circular cylindrical surface. the x axis is defined as zero and thets can be negative if desired. this option is important as a discontinuity of 360 degrees in the angular function at the x axis is not permitted
THETF	E,F	angle in degrees that specifies the finishing boundary for a set of general elements around the partial circumference of a right circular cylindrical surface. the x axis is defined as zero and thetf must be positive. however it can be either larger or smaller than the magnitude of thets
AXL3	E,F	axial coordinate of the third row of structural nodes in the circumferential direction that couple with a particular set of cylindrical surface general elements. if axl3 is non-zero then it must be algebraically greater than axl2 and this row will then form the right axial boundary of the set of fluid elements. this case is characterized by ntcy = 6 with

Variable	Type	Description
		kfun = 1, or ntcy = 9
CYLTRN	E,F	x, y, and z direction translations of circular cylindrical surface fluid node points. will be applied after rotation of coordinates (see cylang below)
CYLANG	E,F	eulerian angles of rotation used to orient the axis of cylindrical surface general elements (see geoang for general definition). in the following special cases of importance the desired axis is shown in the left hand column while the appropriate angles are given to the right: x - 90, 180, 90 or 0, +/-90, 0 y - 0, 90, 90 or +/-90, 0, 0 z - no input, set krot = 0 this option is necessary when using stags as the structural processor in its default mode in which case it uses the x direction as the cylinder axis
N1	I	grid point number of structural node that defines the beginning of a surface of revolution branch or segment
N2	I	grid point number of structural node that defines the end of a surface of revolution branch or segment
R1	E,F	radius to wet surface from axis of surface of revolution element at structural grid point defining the start of a sor branch or segment
R2	E,F	radius to wet surface from axis of surface of revolution element at structural grid point defining the end of a sor branch or segment
NSET	I	number of data records required to define surface of revolution fluid elements along the length of a particular sor branch or axis. if nset = 1 it is assumed that the physical configuration of the sor branch is as described below under iseg
N3	I	grid point number of structural node that defines the axis of the surface of revolution branch in conjunction with n1 if n2 = n1. this case corresponds to a disc. it is advisable that this node be one whose location relative to n1 be in a positive direction along the beam axis even if a temporary structural node must be entered by hand (see nstrc). this is important in preserving symmetry in a problem with identical discs in a structure with end to end symmetry
ISEG	I	number of surface of revolution elements that can be defined between two axial stations such that the radius of the surface varies linearly along the length and that every pair of intermediate adjacent structural node numbers differ by a common incremental value. this need not imply equal axial spacing of the sor elements as the structural nodes may not necessarily be equally spaced along the axis
NUMCHG	I	number of structural grid points that must be renumbered in the fluid-structure transformation data
NODOLD	I	structural grid point number that is to be changed to nodnew in the fluid-structure transformation data
NODNEW	I	new structural grid point number assigned to fluid-structure transformation data in place of nodold. this grid point must already be part of the structural node global

Variable	Type	Description
		coordinate data from input records and/or permanent file
X1	E,F	global coordinate of a reference point on the symmetry axis of a rotationally symmetric fluid mesh surface
Y1	E,F	global coordinate of a reference point on the symmetry axis of a rotationally symmetric fluid mesh surface
Z1	E,F	global coordinate of a reference point on the symmetry axis of a rotationally symmetric fluid mesh surface
X2	E,F	global coordinate of a second reference point on the symmetry axis of a rotationally symmetric fluid mesh surface
Y2	E,F	global coordinate of a second reference point on the symmetry axis of a rotationally symmetric fluid mesh surface
Z2	E,F	global coordinate of a second reference point on the symmetry axis of a rotationally symmetric fluid mesh surface
MHAR	I	harmonic index for rotationally symmetric surface fluid mass matrix
DANG	E,F	included angle in degrees that defines a circumferential segment of a rotationally symmetric fluid mesh surface

3.2 INPUT DATA RECORDS FOR AUGMAT PROCESSOR.

GENERAL PROBLEM DEFINITION (MAIN PROGRAM AUGMAT):

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STRNAM	FLUNAM	GEONAM	PRENAM
FRWTGE	FRWTST	FRWTFL	LUMPFM
FLUSKY	DAAFRM	SYMCON	DOFTAB
PRTGMT	PRTTRN	PRTSTF	PRTAUG
MODTRN	STRLCL	INTWAT	CFADYN

IF FRWTST = .FALSE. OR CAVFLU = .TRUE. (IN FLUMAS) INCLUDE THE FOLLOWING RECORD

MAINKY

NTYPDA

IF NTYPDA = 4 INCLUDE THE FOLLOWING RECORD

DAA2M

NSTR NSFR NFRE NFTR

IF PRTSTF = .TRUE. INCLUDE THE FOLLOWING RECORD
(IGNORE FOR SKYNOM)

NUMBLK NWDBLK

IF THE FLUID MODEL CONSISTS OF ONLY SURFACE OF REVOLUTION ELEMENTS
SKIP THE FOLLOWING SET OF RECORDS

NSETLC
NDICOS JSTART JSTOP JINC)
. . . .) TOTAL = NSETLC
. . . .)

MODIFY FLUID-STRUCTURE TRANSFORMATION (SUBROUTINE CHGTRN):

IF MODTRN = .TRUE. INCLUDE THE FOLLOWING RECORDS

NCHG
ICHG NNOD)
NTEMP(I), I = 1,NNOD)
TEMP(I), I = 1,NNOD)
...)
...) TOTAL = 3*NCHG
...)
...)
...)
...)

REDEFINE STRUCTURAL NODE NORMAL (SUBROUTINE LOCNOR):

IF STRLCL = .FALSE. SKIP THE FOLLOWING SET OF RECORDS

NLOCAL
LOCA IFLS IFLF IFLI ISTS ISTF ISTI)
. . . .) TOTAL = NLOCAL
. . . .)

DEFINE WATER-BACKED STRUCTURAL NODES (SUBROUTINE WETBAC):

IF INTWAT = .TRUE. INCLUDE THE FOLLOWING RECORDS

NUMWET
NSTART NSTOP NINC)
. . .) TOTAL = NUMWET
. . .)

SET SYMMETRY CONSTRAINTS (SUBROUTINE CONSTR):

IF SYMCON = .TRUE. INCLUDE THE FOLLOWING RECORDS

NUMCON
ICON NSTART NSTOP NINC)
. . . .) TOTAL = NUMCON
. . . .)

READ STRUCTURAL MESH FILE (SUBROUTINE STELEM):

IF BOTH CAVFLU (IN FLUMAS) AND FRWTST = .TRUE. READ THE FOLLOWING RECORD

GRDNAM

DISPLAY SKYLINED STRUCTURAL STIFFNESS MATRIX (SUBROUTINE STFMAT):

IF PRTSTF = .TRUE. INCLUDE THE FOLLOWING RECORDS

PRTPNT PRTVAL MAPVAL
MVR1 MVR2

DEFINITION OF INPUT PARAMETERS

Input variable names given below are generally those which are also used in the coding and the variable types correspond to standard fortran usage:

A - alphanumeric
E - floating point
F - fixed point
I - integer
L - logical

Variable	Type	Description
STRNAM	A	name of permanent mass storage file which contains the structural mass and stiffness matrices as well as bookkeeping information relating the internal and external degrees of freedom. when interfacing with the nonlinear structural analyzer stags the stiffness matrix is not present and this is the fortran file created by stags1 on unit 4. the mass and stiffness matrices may be either single or double precision and usa will determine which is the case without any user input. if usa is run in the stand alone version and skynom utilities are used to process the linear structural stiffness matrix, then this file will be a `nominal' global access library (gal) database
FLUNAM	A	name of permanent mass storage file which contains either the fluid mass matrix or its manipulated daa form
GEONAM	A	name of permanent mass storage file which contains the fluid mesh geometry and fluid-structure transformation data
PRENAM	A	name of permanent mass storage file created by this processor which contains all the information required to conduct the underwater shock analysis of the structure in question except for the excitation and integration data
FRWTGE	L	true if the permanent file containing the fluid mesh geometry was created by buffered fortran write statements, otherwise false. this variable will be true for the stags interface
FRWTST	L	true if the permanent file containing the structural mass and stiffness matrices was created by buffered fortran write statements, otherwise false
FRWTFL	L	true if the permanent file containing the fluid mass matrix was created by buffered fortran write statements, otherwise false
LUMPFM	L	true if a diagonal form of the fluid mass matrix is to be constructed from the full version, otherwise false. the specific algorithm incorporated here is due to steve zilliacus and the user is cautioned to use this capability only in an experimental capacity as this is only an approximation that has not been fully evaluated. one known deficiency is the inability to produce the correct asymptotic velocity of the structure once the incident wave has passed. further evaluation of the method remains to be done
FLUSKY	L	true if the fluid mass matrix has been stored in skyline form, otherwise false. if the fluid mass matrix has been computed in an out-of-core mode then this variable must be set to true as the matrix is already in skyline form by default
DAAFRM	L	true if the stored fluid matrix consists of the inverted fluid mass matrix which has been pre- and post-multiplied by the diagonal fluid element area matrix and then multiplied by both the mass density and the speed of sound of the fluid. the resulting matrix is the most convenient form for use in the daa equation. if false then this processor will do the job
SYMCON	L	true if translational constraints must be applied to structural nodes due to symmetry conditions if half or quarter models are being used, otherwise false. constraints on rotational structural freedoms do not enter the augmented matrices. constraints must be applied only if ndicos = 0 (see below)
DOFTAB	L	true if degree of freedom table is already in the proper form for usa, otherwise false. dial is the only structural code for which a value of true is always entered. either option may be valid for the stags code depending upon the type of analysis being conducted. if the linear stiffness matrix is being used in either the sweeps or timint processors, this

Variable	Type	Description
		variable is true. if the usa-stags code is being run, this variable is false
PRTGMT	L	true if fluid mesh geometry data is to be listed, otherwise false
PRTTRN	L	true if fluid-structure transformation data is to be listed, otherwise false
PRTSTF	L	true if skylined structural stiffness matrix is to be displayed, otherwise false. when interfacing with stags this variable must always be taken as false since the global stiffness operator does not exist in the same form as that for usa in the stand alone configuration
PRTAUG	L	true if augmented form of matrices appearing in the fluid equations are to be printed, otherwise false. the first matrix shown is the inverse form of the structural mass and it is the only sparse matrix in the fluid equations. hence a map of its connectivity is always shown. the next matrix is a combination of both the fluid and structure inverse mass matrices. for daa2 runs two additional matrices appear that involve only the fluid mass inverse. the first comes directly from the daa1 equation while the second is its iterated form that appears in the daa2 equation. it is recommended that a value of false be used under normal conditions
MODTRN	L	true if the fluid-structure transformation coefficients are to be modified by substitution of user selected values from the input data stream
STRLCL	L	true if the local normal direction must be changed for some structural node points associated with particular fluid elements. always use false for the usa-stags code, however if stags is used to generate a linear stiffness matrix for a stand alone usa analysis, this variable could be true. this is required for nodes at juncture of cylindrical shell and flat end plate when structural response variables are referred to a local coordinate system as in the stags code. typically the third degree of freedom is normal to shell or plate elements. for an end plate the nodes along the juncture will have the first degree of freedom in the axial direction as the end plate is `slaved' to the cylinder axis system. structural nodes on the end plate that are not on the juncture will have the third degree of freedom in the axial direction. hence `ndicos' (see below) is not the same for all structural nodes coupled to an end plate fluid element at the juncture. if `strmas' was true in the flumas run this option is unnecessary as only one structural freedom is coupled to a fluid freedom
INTWAT	L	true if the wet doubly asymptotic approximation is to be used to obtain an early time solution for a structure with both air-backed and water-backed regions, otherwise false
CFADYN	L	true if this run involves a cavitating fluid volume analysis with the dyna structural code, otherwise false
MAINKY	A	identifying name to be associated with the datasets in the gal database containing the structural mass and stiffness matrices, maximum of 16 characters, ignore for skypul77
NTYPDA	I	this parameter identifies the precise form of the daa fluid-structure interaction equations to be used in the transient response analysis. there are eight (8) possible options as described below: 0 - plane wave analysis 1 - first order daa, this is the required option if the cavitating fluid analyzer is used with the usa code for the external fluid only implementation, ie., 'intcav' = .false. in flumas. if 'intcav' = .true. then any of these options can be used

Variable	Type	Description
		2 - second order daa, matched asymptotic expansion form with curvature effects. the user must ensure that wet-surface radii have been entered in the flumas run 3 - second order daa, felippa form with curvature effects. the user must ensure that wet-surface radii have been entered in the flumas run 4 - second order daa, geers modal form, requires `daa2m' coefficient bounded by zero and unity. if a value of zero or less is entered, the run is reduced to a daa1 calculation 5 - second order daa, special purpose option for surfaces of constant curvature: the sphere and the infinite cylinder 10 - plane wave analysis for the usa code to function as a radiation boundary for acoustic volume elements in the ls-dyna3d code 11 - first order daa analysis for the usa code to function as a radiation boundary for acoustic volume elements in the ls-dyna3d code option 2 is theoretically the most accurate second order doubly asymptotic approximation currently in the usa code and it should be noted that both options 2 and 3 lead to a nonsymmetric set of fluid equations in contrast to the other four possibilities that are symmetric. in addition, these two options require input of wet-surface radii in flumas. If all curvatures are zero, then an error exit will be taken. the zero curvature case is equivalent to option 4 with the `daa2m' parameter equal to unity. options 10 and 11 are applicable only to the usa/ls-dyna3d code
DAA2M	E,F	a parameter bounded by zero and unity that governs the use of the modal form of the second order doubly asymptotic approximation due to geers. this quantity is required only for the daa2 option `ntypda' = 4. a value of zero reduces the fluid solution to the first order doubly asymptotic approximation, however a precise choice for this parameter is not given by any fundamental principle. it has been observed that a value of 1.0 leads to the best accuracy for a spherical shell while a value of 0.5 seems to be best for the infinite cylindrical shell. it can be shown that this scalar parameter does have a relationship with the diagonal local curvature matrix for the fluid elements
NSTR	I	number of node points in structural model
NSFR	I	number of structural degrees of freedom. when running with the usa-stags code this will be six (6) times the value of nstr. if usa is being executed with the linear stiffness matrix from stags the number of degrees of freedom can be found from the stagal run. when running with the usa-dyna code this will be three (3) times the value of nstr
NFRE	I	the largest degree of freedom index at any structural node which is referenced in the analysis. freedoms 1, 2, and 3 are assumed to be translational while 4, 5, and 6 are reserved for rotations. always use six (6) when interfacing with stags, and use three (3) when interfacing with dyna
NFTR	I	the largest translational degree of freedom index at any node which is referenced in the analysis. always use three (3) when interfacing with stags
NUMBLK	I	number of blocks or matrix value records into which the skylined structural stiffness matrix has been partitioned
NWDBLK	I	maximum block size for skylined structural stiffness matrix
NSETLC	I	number of data sets needed to define the type of structural coordinate system with which any particular general fluid element must interface. this data is not required for

Variable	Type	Description
		surface of revolution fluid elements
NDICOS	I	designates the type of coordinate system used in the structural solution. acceptable values are: 0 - global coordinates (use for usa-stags code) 1 - local coordinates with the first degree of freedom normal to the fluid-structure contact boundary 2 - local coordinates with the second degree of freedom normal to the fluid-structure contact boundary 3 - local coordinates with the third degree of freedom normal to the fluid-structure contact boundary at this time options 1, 2, or 3 may be used only for surfaces with unique normals such as spheres or ellipsoids. the only exception to this requirement is a ninety degree intersection, such as is found in a right circular cylinder with an end plate for which some special input is necessary. for more details on this case see `strlcl' above. more latitude in these choices is ultimately planned. for usage with the usa-stags code for transient analysis of linear or nonlinear structural behavior a value of 0 must always be used as stags carries out its own global to local transformation. if stags is used to produce a linear structural stiffness matrix for use in the stand alone usa or sweeps codes, the stiffness matrix may be provided in either global or local coordinates depending upon the user input or model details. global coordinates are automatically set in this processor for all surface of revolution fluid elements. in the event that strmas is true in the flumas run, there is a juncture between a cylinder and a flat end plate, only a portion of the cylinder is modeled in the circumferential direction due to a symmetry plane, and, the structural stiffness matrix is referred to local coordinates then some special input is required. this affects the fluid elements on the lateral surface of the cylinder that are associated with the structural nodes on the juncture line and at the symmetry planes. the fluid node points in this case will be slightly away from the structural node, both axially and circumferentially. hence the outward unit normal vectors will have a small component across the symmetry plane that must be suppressed. to do this, ndicos must take on the value of 10 times the normal degree of freedom number in the local system (10 x 3 = 30 for stags) and add 1, 2, or 3 (for x, y, or z) to indicate the global axis that is parallel to the projection of the actual unit normal vector on the symmetry plane. attention need not be paid to whether the projection is in the positive or negative global direction
JSTART	I	first of one or more fluid elements having the same value of ndicos
JSTOP	I	last of one or more fluid elements having the same value of ndicos
JINC	I	increment to be applied in assigning the value of ndicos to fluid elements in the range from jstart to jstop
NCHG	I	number of data sets required to define the fluid-structure transformation coefficient modifications
ICHG	I	fluid control point number whose fluid- structure transformation coefficients are to be changed
NNOD	I	number of structural nodes to be coupled to fluid control point ichg

Variable	Type	Description
NTEMP	I	structural node numbers coupled to fluid control point ichg
TEMP	I	lumping ratios for specified structural nodes in identical order. the values must total to unity
NLOCAL	I	number of data sets required to redefine the local normal direction for structural nodes associated with fluid elements on flat end caps that join with a cylindrical surface (see strlcl)
LOCA	I	1, 2, or 3 corresponding to a local x, y, or z direction, respectively
IFLS	I	first of one or more fluid elements that require a redefinition of the local normal direction for one or more structural nodes associated with it
IFLF	I	last of one or more fluid elements that require a redefinition of the local normal direction for one or more structural nodes associated with it
IFLI	I	increment to be applied in assigning the value of loca to fluid elements in the range from ifls to iflf
ISTS	I	first of one or more structural node numbers whose local normal direction must be redefined for a particular set of fluid elements
ISTF	I	last of one or more structural node numbers whose local normal direction must be redefined for a particular set of fluid elements
ISTI	I	increment to be applied in assigning the value of loca to structural nodes in the range from ists to istf
NUMWET	I	number of data sets required to define any water-backed structural nodes appearing in the model for an early time solution with the wet doubly asymptotic approximation
NSTART	I	first of one or more structural nodes having a common attribute
NSTOP	I	last of one or more structural nodes having a common attribute
NINC	I	increment to be applied in assigning a common attribute to structural nodes in the range from nstart to nstop
NUMCON	I	number of data sets required to define the constraints to be applied to translational structural degrees of freedom due to symmetry conditions
ICON	I	will have the value 1, 2, or 3 depending upon whether the translational constraint is to be applied in the x, y, or z global coordinate direction. constraints to the augmented matrices are required only if a fluid element associated with a particular structural node is oriented such that the unit outward normal vector of the fluid element has a component perpendicular to the symmetry plane. for example, a quarter cylinder model would require a circumferential constraint but not an axial one
GRDNAM	A	name of permanent mass storage file that contains the global coordinates of the structural grid points. for the stags structural code this file will also contain the element connectivity data if it is the fortran file created by stags1 on unit 3. the element connectivity will also be in this file if it is a gal (global access library) database created by either the stagal processor (for stags) or nassky (for nastran). in this case frwtst must

Variable	Type	Description
		be false
PRTPNT	I	a value of one (1) will produce a display of the diagonal location pointers of the skylined structural stiffness matrix, otherwise set to zero under normal conditions
PRTVAL	I	a value of one (1) will produce a display of the skylined stiffness matrix while a value of five (5) will cause only the diagonal terms to be printed, otherwise set to zero. use a value of one only for diagnostic reasons or for very small problems as the amount of output can be enormous
MAPVAL	I	a value of one (1) will produce a map-type display of matrix values to show the connectivity alone, otherwise set to zero under normal conditions
MVR1	I	index of first matrix value record to be displayed. under normal conditions use a value of zero and the code will start the display at the beginning of the matrix. use a non-zero value only when a specific set of blocks is to be printed for some diagnostic reason
MVR2	I	index of last matrix value record to be displayed. under normal conditions use a value of zero and the code will display to the end of the matrix. use a non-zero value only when a specific set of blocks is to be printed for some diagnostic reason

3.3 INPUT DATA RECORDS FOR TIMINT PROCESSOR.

All input data can be typed in a free field format with a blank space or comma used to separate the distinct entries. However, any individual piece of data must not be longer than 10 characters with the exception of file names. File name plus qualifier is restricted to 20 characters

GENERAL PROBLEM DEFINITION (SUBROUTINE INPDAT):

72 COLUMN ALPHANUMERIC TITLE

PRENAM POSNAM STRNEW
RESNAM WRTNAM

FOR THE LINEAR USA CODE READ THIS RECORD

REFSEC FLUMEM VISDMP

FOR THE ELECTRIC BOAT VERSION READ THIS RECORD

MOUNTS USRBUB

FOR THE NONLINEAR USA-STAGS CODE READ THIS RECORD

REFSEC FLUMEM STRVEL

FOR THE NONLINEAR USA-DYNA CODE READ THIS RECORD

REFSEC FLUMEM

NTINT NCHGAL
STRTIM DELTIM)
. .) TOTAL = NTINT
. .)

OMIT THE FOLLOWING RECORD FOR USA-DYNA

FINTM ADAMP BDAMP

INCIDENT WAVE OPTIONS (SUBROUTINE SHKDAT):

EXPWAV SPLINE VARLIN PACKET
HYPERB EXPLOS DOUBDC VELINP
BUBPUL SHKBUB BOTREF

IF VELINP = .TRUE. INCLUDE THE FOLLOWING RECORD

RADVEL SAMTIM

IF BOTREF = .TRUE. INCLUDE THE FOLLOWING RECORD
UNLESS BUBPUL = .TRUE. THEN OMIT

DISTB CXBR CYBR CZBR BNORM

NCHARG

IF CAVFLU = .TRUE. INCLUDE THE FOLLOWING RECORD

HYDPRE PATM

IF CAVFLU = .FALSE. INCLUDE THE FOLLOWING RECORD

HYDPRE

READ THE FOLLOWING RECORDS FOR EACH CHARGE

CHARGE LOCATION DATA (SUBROUTINE CHGLOC):

XC YC ZC
SX SY SZ

IF BUBPUL = .TRUE. SKIP DOWN TO BUBINP

IF REFSEC = .TRUE. SKIP DOWN TO INPDAT
AS REFMS EXCLUDES ANY OTHER CHARGE OPTIONS

TIME HISTORY DATA (SUBROUTINE INCWAV):

JPHIST
PNORM DETIM

IF SPLINE AND VARLIN = .FALSE. INCLUDE THE FOLLOWING RECORD

DTHIST

IF EXPWAV, SPLINE, VARLIN, PACKET = .FALSE. INCLUDE THESE RECORDS

PHIST(I), I=1,JPHIST

IF VELINP = .TRUE. INCLUDE THESE RECORDS

RPVEL(I), I=1,JPHIST

IF VELINP = .TRUE. AND RADVEL = .FALSE. INCLUDE THESE RECORDS

ZPVEL(I), I=1,JPHIST

EXPLOSIVE PARAMETERS DATA (SUBROUTINE CHARGE):

IF EXPWAV = .TRUE. AND EXPLOS = .TRUE. INCLUDE THESE RECORDS

CHGTYP
WEIGHT SLANT CHGDEP

TIME HISTORY DATA (SUBROUTINE INCWAV):

IF EXPWAV = .TRUE. AND EXPLOS = .FALSE. INCLUDE THIS RECORD

PZERO DECAY

IF PACKET = .TRUE. INCLUDE THE FOLLOWING RECORD

PZERO OMEG1 OMEG2

CUBIC SPLINE INCIDENT PRESSURE HISTORY DATA (SUBROUTINE CSPRES):

IF SPLINE OR VARLIN = .TRUE. INCLUDE THE FOLLOWING RECORDS

TIMES(I), I=1,JPHIST
PHIST(I), I=1,JPHIST

IF VELINP = .TRUE. INCLUDE THESE RECORDS

IF SAMTIM = .FALSE. READ THE FOLLOWING TWO RECORDS

NRVEL
TRVEL(I), I=1,NRVEL

RPVEL(I), I=1,JPHIST

IF VELINP = .TRUE. AND RADVEL = .FALSE. INCLUDE THESE RECORDS

IF SAMTIM = .FALSE. READ THE FOLLOWING TWO RECORDS

NZVEL
TZVEL(I), I=1,NRVEL

ZPVEL(I), I=1,JPHIST

BUBBLE PULSE DEFINITION (SUBROUTINE BUBINP):

IF BUBPUL = .TRUE. INCLUDE THE FOLLOWING RECORDS

WGTCHG CFDRAG CONVFT TBCUT DETIM

IF FRESUR = .FALSE. IN FLUMAS RUN INCLUDE THIS RECORD

MIGRAT

IF SHKBUB = .FALSE. INCLUDE THIS RECORD

CHGTYP

IF CHGTYP = 6 INCLUDE THE FOLLOWING RECORD

BUBPER BUBRAD

IF FRESUR = .FALSE. IN FLUMAS RUN INCLUDE THIS RECORD

DEPTH CXFS CYFS CZFS

DEFINITION OF VERTICAL DIRECTION (SUBROUTINE SHKDAT):

IF VELINP = .TRUE. AND REFSEC, RADVEL, AND FRESUR = .FALSE.
INCLUDE THIS RECORD

CXFS CYFS CZFS

GENERAL PROBLEM DEFINITION (SUBROUTINE INPDAT):

IF HYPERB = .TRUE. INCLUDE THE FOLLOWING RECORD

CETA CNU CLEN DETIM

GENERAL PROBLEM DEFINITION (SUBROUTINE INPDAT):

FOR THE NONLINEAR USA-STAGS CODE READ THIS RECORD

NSAVER NRESET NSODFL

OTHERWISE READ THIS RECORD

NSAVER NRESET

READ THIS RECORD FOR THE STANDARD USA VERSIONS

LOCBEG LOCRES LOCWRT NSTART

OTHERWISE READ THIS REORD FOR THE ELECTRIC BOAT VERSION

LOCBEG LOCRES LOCWRT LOCMNT NSTART

FORWRT STBDA2 ASCWRT

IF CAVFLU = .TRUE. IN FLUMAS INCLUDE THE FOLLOWING RECORD

NOAMBI PRTVOL PRTINI

USA RADIATION BOUNDARY FOR LS-DYNA3D (SUBROUTINE INIDAA):

IF NTYPDA = 10 OR 11 IN AUGMAT INCLUDE THE FOLLOWING RECORDS

XVYVZV

IF FRESUR = .FALSE. IN FLUMAS INCLUDE THE FOLLOWING RECORDS

DEPTH CXFS CYFS CZFS
PATM GRAVAC

FLUID VOLUME DEFINITION (SUBROUTINE CAVDAT):

IF CAVFLU = .TRUE. IN FLUMAS INCLUDE THE FOLLOWING RECORDS

FVBET0 FVBET1
ICAVSW IORDF IORDV
NFVWAV NFVELM NFVNOD

IF REFSEC = .TRUE. INCLUDE THE FOLLOWING RECORD(S)

IF FRESUR = .FALSE. IN FLUMAS RUN INCLUDE THIS RECORD

CXFS CYFS CZFS

REFNAM

<u>POST PROCESSING (SUBROUTINE POSTRE):</u>

DISPLA

IF DISPLA = .FALSE. THIS TERMINATES THE INPUT DATA DECK

NPREVT NPREVF

IF NPREVF NOT = 0 INCLUDE THE FOLLOWING RECORDS

NTIMES(I), I=1,NPREVF
XVPNAM(I), I=1,NPREVF

<u>POST PROCESSING (SUBROUTINE RESDSP):</u>

LISTRE PRTPLT

<u>POST PROCESSING (SUBROUTINE STRDSP):</u>

IF NSTR = 0 (IN AUGMAT) IGNORE DISPLACEMENT AND VELOCITY INPUT

NWETHS NDRYHS NUMSET
NODOUT NFROUT
. .
. .
NODOUT NFROUT NEQHST
. . .
. . .
. . .
IF NUMSET = 0 OMIT THE FOLLOWING RECORDS
NFROUT NODFIR NODLAS NODINC
. . . .
. . . .

TOTAL = NWETHS

TOTAL = NDRYHS

TOTAL = NUMSET

THIS SET FOR DISPLACEMENTS

NWETHS NDRYHS NUMSET
NODOUT NFROUT
. .
. .
NODOUT NFROUT NEQHST
. . .
. . .
. . .
IF NUMSET = 0 OMIT THE FOLLOWING RECORDS
NFROUT NODFIR NODLAS NODINC
. . . .

TOTAL = NWETHS

TOTAL = NDRYHS

TOTAL = NUMSET

THIS SET FOR VELOCITIES

. . . .))

POST PROCESSING (SUBROUTINE RESDSP):

NPREHS NUMSET
NEQHPR IPRS)
.) TOTAL = NPREHS
.)

IF NUMSET = 0 OMIT THE FOLLOWING RECORDS

NODFIR NODLAS NODINC IPRS)
. . .) TOTAL = NUMSET
. . .)

POST PROCESSING (SUBROUTINE FILBUF):

SCALEF

IF SCALEF = .TRUE. INCLUDE THE FOLLOWING RECORD

RESFAC PREFAC TIMFAC

DEFINITION OF INPUT PARAMETERS

Input variable names given below are generally those which are also used in the coding and the variable types correspond to standard fortran usage:

A - alphanumeric
E - floating point
F - fixed point
I - integer
L - logical

Variable	Type	Description
PRENAM	A	name of pre-processed mass storage file containing all fluid and structure data that does not depend upon the shock input and time integration parameters
POSNAM	A	name of mass storage file available for post-processing which contains system responses
STRNEW	A	leave blank for normal usage, otherwise this is the name of a different structural stiffness matrix file that is to be used in the time integration run rather than the one used in the augmat processor. the only conditions under which this abnormal case can be used are when the structure and its mass are the same as before, but its elastic constants are different as often occurs in parameter studies. in such cases augmat need not be rerun
RESNAM	A	name of mass storage file that contains information for restarting the transient response analysis
WRTNAM	A	name of mass storage file upon which restart data is to be written. if left blank then restart data will be written on the file denoted by resnam
REFSEC	L	true if the incident wave fluid pressure and particle velocity data is to be read from a file produced by the refms code, otherwise false. this option excludes any other standard charge inputs
FLUMEM	L	true if the various daa fluid matrices are to be kept in memory during the transient response analysis, otherwise false in which case they will be read in for every time step as in older versions of the code. the use of this option depends upon the amount of memory available to the user and can cut the i/o usage by up to an order of magnitude. this option must be balanced by a consideration of i/o costs versus availability and cost of memory. the parameter maxcor may need to be adjusted in the source code and an error exit will be taken if there is insufficient memory. an appropriate user friendly message will be printed in this event
VISDMP	L	true if a user supplied viscous damping matrix for the structure is to be used. this capability exists only for the skynom gal database version of usa and this matrix must be an additional dataset in the gal structural database. this feature can also be used in conjunction with rayleigh damping (see adamp and bdamp)
STRVEL	L	true if the problem is one of a prescribed initial velocity of the structure with no incident pressure wave excitation. this capability only exists with usa-stags at this time
NTINT	I	number of time step sizes to be used in the integration process. see above for maximum number allowed by core allocation
NCHGAL	I	valid only for daa2 runs with a number of time step size increases in which very late time structural response information is required. this is the index of the step size (currently from 1 to 10) at which the structural time integration algorithm is to be changed from trapezoidal rule to a cross between that and backward euler in order to enhance stability of the daa2 integration. although the daa2 integration is not unconditionally stable like the daa1 integration it does possess a substantial time step range over which it is stable. this option is a means of extending that range at the possible cost of some loss of accuracy. leave blank or use a value of zero if this option is not desired (also see stbda2)
STRTIM	E,F	the starting time at which any particular step size is to be used until it is either superseded by another step size or, the entire transient analysis has been completed

Variable	Type	Description
DELTIM	E,F	time step size associated with strtim above
FINTM	E,F	time at which the present analysis is to be terminated
ADAMP	E,F	coefficient of structural damping that is proportional to mass matrix and can be used in conjunction with a user supplied viscous damping matrix (see visdmp). if this is a usa-stags or usa-stags-cfa run, the value entered here will override that used in the stags model input data. hence, this parameter should not be left zero if there is a non-zero value in the stags input
BDAMP	E,F	coefficient of structural damping that is proportional to stiffness matrix and can be used in conjunction with a user supplied viscous damping matrix (see visdmp). if this is a usa-stags or usa-stags-cfa run, the value entered here will override that used in the stags model input data. hence, this parameter should not be left zero if there is a non-zero value in the stags input
EXPWAV	L	true if the incident pressure pulse is expressed in the form of an exponentially decaying function, otherwise false. this variable must also be true if explos is true (see below). it is recommended that the pressure history be defined over four decay times to ensure that it drops to zero smoothly: 4*decay = dthist*(jphist-1) (see below for definition of variables)
SPLINE	L	true if the incident pressure pulse is described by a cubic spline function. care should always be taken with the choice of input data points since this algorithm will produce a continuous function that can oscillate wildly around areas of rapid change. in such cases it is important to cluster data points in these areas
VARLIN	L	true if the incident pressure pulse is described by a variable linear spacing, otherwise false
PACKET	L	true if the incident pressure pulse is a modulated sinusoidal wave packet described by the product of sin(omeg1*t) and sin(omeg2*t), otherwise false. if either circular frequency is zero the modulation of the non-zero frequency will be a square wave
HYPERB	L	true if the incident wave front is to be approximated as hyperbolic, otherwise false in which case the front is spherical. currently do not use this option with incident pressure history data with variable spacing in time
EXPLOS	L	true if the incident wave fluid pressure data is to be found for an exponentially decaying wave from the characteristics of the charge weight and location. expwav above must also be true if this is the case. required input data must be in pounds and distances must be in feet. the pressure history will then be in psi. if some other unit system is being used such as metric, then the variable pnorm below can be used for a conversion factor
DOUBDC	L	true if the double decay model of the exponentially decaying incident wave is to be used, otherwise false. this form uses the specified decay time out to a time of 1.4 times the decay time, but, past this value, a second decay time is used that is equal to 2.9 times the original decay time. at the transition point the pressure has dropped to 24.66 percent of its peak value and then decays much more slowly after that
VELINP	L	true if the fluid particle velocity history of the incident wave is to be input in addition to the pressure history, otherwise false. in the event that the case involves a free surface, the inputs for pressure and velocity must include all effects of the free surface cutoff due to bulk cavitation and the cutoff model in the code will not be used. this input option

Variable	Type	Description
		assumes that the incident wave histories are those from free field test data
BUBPUL	L	true if the incident fluid pressure and particle velocity are due to a pulsating and migrating explosion gas bubble, otherwise false. when this option is true, the virtual mass approximation is used for the fluid-structure interaction equations by default unless the variable daa2m was greater than zero in the augmat input. in this case the daa2 equations are used. the daa1 cannot be used for bubble loadings as it is not sufficiently accurate. this option does not allow the use of bottom reflections (see botref below)
SHKBUB	L	true if a combined shock and bubble analysis is to be conducted, otherwise false. this capability is not currently operational
BOTREF	L	true if bottom reflections are included in the analysis, otherwise false. the model currently in use assumes a flat bottom and a user supplied reflection coefficient `bnorm' (see below) ranging from zero to unity. this capability does not use a modified fluid mass matrix as does the free surface option, hence the late time behavior of the structure may not be adequately represented if the structure is very close to the bottom. this option cannot be used with bubble pulse analysis (see bubpul above)
RADVEL	L	true if the fluid particle velocity history input data corresponds to the radial component from a spherical charge. this would be the line of sight direction from the charge location to the standoff point on the structure closest to the charge, otherwise false in which case both horizontal and vertical component histories are expected to be read
SAMTIM	L	this variable applies only to the case of fluid particle velocity input along with either the `varlin' or `spline' options being used. the choice of true indicates that the velocity history points input correspond to the same time points as for the pressure history, otherwise false in which case time data for the velocities must then be read in as well
DISTB	E,F	perpendicular distance to the bottom from the origin of the global cartesian coordinate system and consistent with the following unit normal vector data
CXBR	E,F	direction cosine of a unit vector normal to the plane of the bottom and pointing out of the fluid region, ie., into the bottom. it must be relative to the global cartesian coordinates of the fluid mesh
CYBR	E,F	direction cosine of a unit vector normal to the plane of the bottom and pointing out of the fluid region, ie., into the bottom. it must be relative to the global cartesian coordinates of the fluid mesh
CZBR	E,F	direction cosine of a unit vector normal to the plane of the bottom and pointing out of the fluid region, ie., into the bottom. it must be relative to the global cartesian coordinates of the fluid mesh
BNORM	E,F	a user supplied reflection coefficient for bottom reflections ranging from zero to unity
NCHARG	I	number of charges for which locations and time histories are to be input. only one charge is currently allowed for options in which `bubpul' or `refsec' are true
HYDPRE	E,F	ambient hydrostatic pressure acting on structure at depth before and during the transient response analysis, applicable only to usa-stags runs when restarting from a static load case

Variable	Type	Description
PATM	E,F	ambient atmospheric pressure that is used ultimately to test for bulk cavitation in the underwater shock analysis
XC	E,F	cartesian coordinate x of the location of spherical charge in fluid mesh system. if hyperb = .true. the incident wave emanates from a line charge and the data required here is the point of the line charge that is closest to the structure. the charge in this case is oriented along the line joining this point and the standoff point
YC	E,F	cartesian coordinate y of the location of spherical charge in fluid mesh system. if hyperb = .true. the incident wave emanates from a line charge and the data required here is the point of the line charge that is closest to the structure. the charge in this case is oriented along the line joining this point and the standoff point
ZC	E,F	cartesian coordinate z of the location of spherical charge in fluid mesh system. if hyperb = .true. the incident wave emanates from a line charge and the data required here is the point of the line charge that is closest to the structure. the charge in this case is oriented along the line joining this point and the standoff point
SX	E,F	cartesian coordinate x of the charge standoff point in the fluid mesh system. this is the point on the daa boundary that is closest to the charge. for all but the external fluid volume element version of usa-stags-cfa this point is on the wet surface of the structure. in this case the integration process starts at time equal to zero with the incident wave just touching the daa boundary at this point associated with the minimum distance to the charge. for usa-stags-cfa with external fluid volume elements time is equal to zero with the incident wave touching a volume node specified by the user (see nfvwav)
SY	E,F	cartesian coordinate y of the charge standoff point in the fluid mesh system. this is the point on the daa boundary that is closest to the charge. for all but the external fluid volume element version of usa-stags-cfa this point is on the wet surface of the structure. in this case the integration process starts at time equal to zero with the incident wave just touching the daa boundary at this point associated with the minimum distance to the charge. for usa-stags-cfa with external fluid volume elements time is equal to zero with the incident wave touching a volume node specified by the user (see nfvwav)
SZ	E,F	cartesian coordinate z of the charge standoff point in the fluid mesh system. this is the point on the daa boundary that is closest to the charge. for all but the external fluid volume element version of usa-stags-cfa this point is on the wet surface of the structure. in this case the integration process starts at time equal to zero with the incident wave just touching the daa boundary at this point associated with the minimum distance to the charge. for usa-stags-cfa with external fluid volume elements time is equal to zero with the incident wave touching a volume node specified by the user (see nfvwav)
JPHIST	I	number of incident pressure history data points. see above for maximum number allowed by core allocation. for the case of multiple input charges, a negative value can be used to denote that the pressure history for this incident wave is the same as that of a previously input pressure history. for example, a value of -2 would indicate that the history data is the same as for charge number 2
PNORM	E,F	constant multiplicative factor to be applied to the input pressure history data points
DETIM	E,F	detonation time of charge
DTHIST	E,F	time interval associated with any two successive incident pressure history data points. for exponentially decaying waves it is recommended that dthist*(jphist-1) be no less that

Variable	Type	Description
		4*decay (see below). this will ensure that the tail of the wave will have decreased to 1.83 percent (e**-4) of its peak value before it is truncated and set to zero for subsequent times
PHIST	E,F	incident pressure history data points. the values used in the time integration process are the product of phist and pnorm to allow for the possibility that the input data may have been experimentally obtained at a point which is not equal to sc above. pnorm must therefore reflect the 1/r scaling difference between sc and the location of the pressure sensor during the pulse characterization experiment. if the incident pressure goes to zero at some point and remains there then data need only be provided for that time span and the code will automatically ensure that the incident pressure remains zero thereafter. when restarting the transient analysis the required incident pressure data is identical to that used in the initial run. if spline is false then the pressure history data must be equally spaced in time with the increment dthist. if spline is true the pressure history data can be unequally spaced according to data provided in times (see below). when using the spline capability the last pressure data point must be zero so that the code can automatically generate zero pressures beyond that point. otherwise an out-of-range error exit will be taken
RPVEL	E,F	if velinp is true then this is the radial component of the incident wave fluid particle velocity associated with a spherical wave. if velinp is false then this is the horizontal component of the incident wave fluid particle velocity
ZPVEL	E,F	vertical component of incident wave fluid particle velocity history data
CHGTYP	I	indicator to denote type of explosive used for charge, allowable values are: 1 - hbx-1 2 - tnt 3 - petn 4 - nuclear 5 - hicks coefficients for bubble period and initial radius 6 - user defined coefficients for bubble period and initial radius options 5 and 6 are valid only for bubble pulse excitation and not for shock wave analysis. it should also be noted that option 5 has been the default bubble case since the capability was first installed in the usa code so that there does not exist a body of experience to draw upon to guide the user when using the other options. in addition, it is not known whether the variable `cfdrag' (see below) would need to be different for the other cases. at this time one should continue to use the value recommended below until there is evidence to the contrary
WEIGHT	E,F	charge weight in pounds for particular explosive chosen. for the nuclear case the weight will be in kilotons
SLANT	E,F	slant standoff in feet regardless of other length units used in fluid and structure models. slant standoff is the distance between the charge and the closest point on the structure
CHGDEP	E,F	charge depth in feet regardless of other length units used in fluid and structure models. this is different from the definition used in the flumas processor and its inclusion here does not imply the existence of a free surface in the problem if the user has not specified one. this parameter effects only the bubble period and initial radius and not the pressure history. it is merely used for secondary information the user might wish to know if the charge depth is given and it has no effect on the results of a shock analysis when the

Variable	Type	Description
		input variable bubpul is false
PZERO	E,F	peak value of pressure for exponentially decaying incident pulse
DECAY	E,F	decay time for exponentially decaying incident pressure pulse. this is the time it takes for the pressure to drop to 1/e (about .36788) of its peak value
OMEG1	E,F	first circular frequency for modulated sine wave packet
OMEG2	E,F	second circular frequency for modulated sine wave packet
TIMES	E,F	time values associated with unequally spaced incident pressure history values
NRVEL	I	number of radial (or horizontal) fluid particle velocity history data points to be input. used only if `samtim' is false
TRVEL	E,F	input time points for radial (or horizontal) fluid particle velocity history data
NZVEL	I	number of vertical fluid particle velocity history data points to be input. used only if `samtim' and `radvel' are both false
TZVEL	E,F	input time points for vertical fluid particle velocity history data
WGTCHG	E,F	charge weight in pounds of tnt or the equivalent weight of tnt for other explosives
CFDRAG	E,F	bubble drag coefficient. a value of 2.25 gives reasonable values for the bubble migration. note that the bubble equations with drag included are valid only while the bubble is migrating upward, hence they are not applicable for small explosions near the surface where downward migration is possible. for explosions of interest on full scale, downward migration does not occur
CONVFT	E,F	a multiplicative length scale factor that converts the users unit of length to feet as the bubble equations have some hard wired constants in them that work only in the pound-feet-second system. if the model and problem dimensions are in inches this value is 1./12. =.0833333
TBCUT	E,F	bubble cutoff time beyond which the user would like to have the structure go into free vibration. this somewhat artificial feature can allow a better assessment of the model's response to the bubble. if a value of zero is entered no cutoff will occur
MIGRAT	L	true if the bubble will be allowed to migrate during the analysis, otherwise false, in which case it will remain fixed in space
BUBPER	E,F	user defined coefficient appearing in the explosive charge equations to define the bubble period
BUBRAD	E,F	user defined coefficient appearing in the explosive charge equations to define the initial bubble radius
DEPTH	E,F	charge depth, this is different from the definition used in the flumas processor. it is also different from `chgdep' above in that it is the same quantity, but in the units of length in which all of the structural and charge geometry are expressed

Variable	Type	Description
CXFS	E,F	direction cosine of a unit vector normal to the plane of the free surface and pointing out of the fluid region. it must be relative to the global cartesian coordinates of the fluid mesh
CYFS	E,F	direction cosine of a unit vector normal to the plane of the free surface and pointing out of the fluid region. it must be relative to the global cartesian coordinates of the fluid mesh
CZFS	E,F	direction cosine of a unit vector normal to the plane of the free surface and pointing out of the fluid region. it must be relative to the global cartesian coordinates of the fluid mesh
CETA	E,F	detonation parameter for hyperbolic wave front approximation, bounded by zero and unity. the upper bound reduces to a spherical wave front emanating from a line charge. do not use unity as the equation system becomes singular
CNU	E,F	detonation parameter for hyperbolic wave front approximation, bounded by zero and unity. avoid using values very close to unity
CLEN	E,F	charge length for hyperbolic wave front approximation. under normal circumstances use zero and the code will assign the appropriate length consistent with the pulse duration and the above parameters ceta and cnu. if clen is specified to be nonzero the pulse duration will be changed
NSAVER	I	frequency of saving system responses on permanent file posnam. nsaver expressed in number of time steps
NRESET	I	frequency of saving restart information on permanent file resnam or wrtnam. nreset is expressed in number of time steps
NSODFL	I	applies only to usa-stags runs and sets the stags variable ipost1 without having to rerun stags1. this is the frequency of saving displacement data for stags post processing, expressed in number of time steps. be aware that if a nonzero value was used in the stags input and this is inadvertently left zero, no data will be saved, making the run worthless
LOCBEG	I	location in posnam file where responses from current run are to be placed. a zero value is the designation of the beginning of the file for either system in this code. if locbeg = 0, a new permanent file is assigned for the run with the name denoted by posnam, otherwise posnam is taken to be an existing file. under restart conditions the appropriate value of locbeg is ascertained from output generated during preceding runs
LOCRES	I	location in permanent file resnam where restart data is to be found. see locbeg for definition of location. set equal to zero if current run is not a restart, otherwise appropriate value of locres is ascertained from output generated during preceding runs
LOCWRT	I	location in permanent file resnam or wrtnam where new restart data generated in the current run is to be written. see locbeg for definition of location. if wrtnam has been left blank (see above) the restart data is written on the same file as that containing the data used to restart the current run. in such a case it is important that locwrt be carefully chosen so that previous data is not inadvertently overwritten. an appropriate value can be found from output generated from preceding runs. if locwrt = zero, a new permanent file is assigned for the run with the name denoted by wrtnam, otherwise wrtnam is taken to be an existing file

Variable	Type	Description
NSTART	I	last time step number for which transient response results have been computed and from which a restart will continue. nstart must not include the initialization step at time = zero. this input only required for usa-stags runs
FORWRT	L	true if permanent file denoted by posnam is to be created using unformatted fortran write. if both forwrt and ascwrt (see below) are false then the response file will be created by direct block i/o using the data management system dmgasp
STBDA2	L	applicable only to daa2 runs. if false, 3 point extrapolation is used for structural coupling vector on right hand side of daa2 equation in staggered solution procedure. value from previous step is used if true. the daa2 integration algorithm is not unconditionally stable like the daa1 is for linear structures but it is stable for fairly large time step sizes with extrapolation. the critical time step is even larger without extrapolation (also see nchgal). for best accuracy, use the default option of false unless a stability problem does actually occur
ASCWRT	L	true if permanent file denoted by posnam is to be created as a formatted ascii file. if both ascwrt and forwrt (see above) are false then the response file will be created by direct block i/o using the data management system dmgasp
XV	E,F	cartesian coordinate x of the location of the wave front of the incident pressure wave at t=0 for the radiation boundary version of usa for ls-dyna3d. this point should be at least one volume element out from the structural node closest to the charge location
YV	E,F	cartesian coordinate y of the location of the wave front of the incident pressure wave at t=0 for the radiation boundary version of usa for ls-dyna3d. this point should be at least one volume element out from the structural node closest to the charge location
ZV	E,F	cartesian coordinate z of the location of the wave front of the incident pressure wave at t=0 for the radiation boundary version of usa for ls-dyna3d. this point should be at least one volume element out from the structural node closest to the charge location
GRAVAC	E,F	acceleration due to gravity
NOAMBI	L	a value of true will ensure that the ambient fluid pressure is not applied to the structure during a usa-stags-cfa analysis but used only for monitoring the onset of cavitation, otherwise false
PRTVOL	L	use a value of true if one desires a list of the fluid volume node point coordinates and element connectivities in a usa-stags-cfa analysis, otherwise false. in general a value of false is recommended
PRTINI	L	use a value of true if one desires a list of the initial values of the fluid volume variables in a usa-stags-cfa analysis, otherwise false. in general a value of false is recommended
FVBET0	E,F	artificial damping coefficient for fluid volume time integration in a usa-stags-cfa analysis. such damping increases with frequency as it is proportional to the time derivative of the cubical dilatation. this term is a nondimensional constant with a range from zero to unity for all fluid volume elements. it is recommended that unity be used in general. a value of zero results in instability
FVBET1	E,F	artificial damping coefficient for fluid volume time integration in a usa-stags-cfa analysis. such damping increases with frequency as it is proportional to the time derivative of the cubical dilatation. this term is a nondimensional constant with a range

Variable	Type	Description
		from zero to unity that is operative only when cavitation is occurring in a particular volume element and provides damping that is proportional to the difference between the ambient hydrostatic pressure and the local pressure in the element at the previous time step. use a value of zero for this term as it has not yet been systematically evaluated
ICAVSW	I	this is a user operated cavitation switch for the usa-stags-cfa version of the code. a value of one (1) will allow cavitation to occur while a value of zero (0) will suppress cavitation and create negative pressures. in general cavitation should be allowed unless one is interested in an assessment of its effects in a particular problem
IORDF	I	order of numerical integration to be used over boundary faces of fluid volume in a usa-stags-cfa analysis. allowable values are: 1 - one point gauss rule 2 - next higher level up a value of 1 is recommended at this time, primarily from a cpu time point of view
IORDV	I	order of numerical integration to be used in fluid volume elements in a usa-stags-cfa analysis. allowable values are 1 - one point gauss rule 2 - next higher level up a value of 1 is recommended at this time, primarily from a cpu time point of view
NFVWAV	I	global fluid volume node point number that is touched by the incident wave at the start of a usa-stags-cfa analysis. this point should be at least one volume element out from the structural node closest to the charge location
NFVELM	I	total number of fluid volume elements in a usa-stags-cfa analysis
NFVNOD	I	total number of fluid volume node points in a usa-stags-cfa analysis
REFNAM	A	name of mass storage file produced by the refms code that contains the incident wave fluid pressure and particle velocity data
DISPLA	L	true if selected transient response histories are to be displayed, otherwise false
NPREVT	I	number of time steps previously computed with responses saved in permanent file denoted by posnam. nprevt will be nonzero only for restart runs but it can be zero under restart conditions if posnam denotes a new response file. the use of nprevt ensures that any transient response display made in conjunction with the time integration run will include the entire history available from that file and not just the portion computed during the current run. if posnam contains the complete transient solution back to time zero then nprevt must be the number of time steps plus one to account for the fact that the initial conditions appear in the first record. if this run is the very first of a particular shock analysis then nprevt will be zero
NPREVF	I	number of response files from previous runs that make up the desired transient analysis display. do not add in the current run as this is done by the code. nprevf presently cannot exceed nine (9)

Variable	Type	Description
NTIMES	I	the number of response records that are stored in any particular response file. these must be ordered chronologically for input. ntimes will generally be the number of time steps made during the time the file was created except if the file goes back to time equal to zero. in this case ntimes is equal to the number of time steps plus one to account for the first record that contains the initial conditions
XVPNAM	A	names of previous response files that make up a continuous set of transient data, ordered chronologically. do not include posnam in this list
LISTRE	L	true if transient response histories are to be listed in tabular form, otherwise false
PRTPLT	L	true if printer plots are to be generated for transient response histories, otherwise false
NWETHS	I	number of structural histories (either displacements or velocities) to be displayed for which the appropriate structural freedoms can be identified internally through the freedom/equation correspondence table. all structural nodes which participate in the fluid-structure transformation will fall into this category as well as any others whose grid point coordinates were entered as data for the fluid mass processor
NDRYHS	I	number of structural histories (either displacements or velocities) to be displayed for which the appropriate structural freedoms cannot be identified internally through the freedom/equation correspondence table. dry structure node points can fall into this category if the user did not include them in the data stream for the fluid mass processor. in this case one must identify the internal sequence number appropriate to the desired degree of freedom by a mystical process which involves the intimate knowledge of the elimination order and any reduction of the number of active freedoms due to the application of constraints. moral of the story - run all structural grid points through the fluid mass processor even if they never get wet
NUMSET	I	number of data sets used to define response displays for several degrees of freedom that differ by a constant increment. this feature can be used to simplify input data to show a number of transient results at different places along a generator of a cylinder or, around the circumference at any axial station
NODOUT	I	external identification number of structural node for which a time history display is desired
NFROUT	I	structural degree of freedom number for which a time history display is desired
NEQHST	I	internal sequence number determined by hand for structural degrees of freedom which are to be displayed and are not included in the freedom/equation correspondence table for reasons known only to the user
NODFIR	I	first of several equally incremented node numbers at which output is desired
NODLAS	I	last of several equally incremented node numbers at which output is desired
NODINC	I	increment to be applied in assigning node numbers for output
NPREHS	I	number of fluid pressure histories to be displayed
NEQHPR	I	fluid node point number for which a time history display is desired for the total pressure. this can be either on a daa boundary or in a fluid volume region (see iprs)

Variable	Type	Description
IPRS	I	a value of zero (0) denotes a daa boundary node while a value of one (1) denotes a fluid volume node
SCALEF	L	true if multiplicative constant factors are to be applied to the displayed values of the structural displacements and velocities, total fluid pressures and/or time, otherwise false. such factors are not applied to the permanent files containing the response histories
RESFAC	E,F	multiplicative length conversion factor to be applied to the displayed values of the structural displacement and velocity histories
PREFAC	E,F	multiplicative pressure conversion factor to be applied to the displayed values of the total pressure histories
TIMFAC	E,F	multiplicative time conversion factor to be applied to the displayed values of the time axis for all the transient response histories

SECTION 4

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